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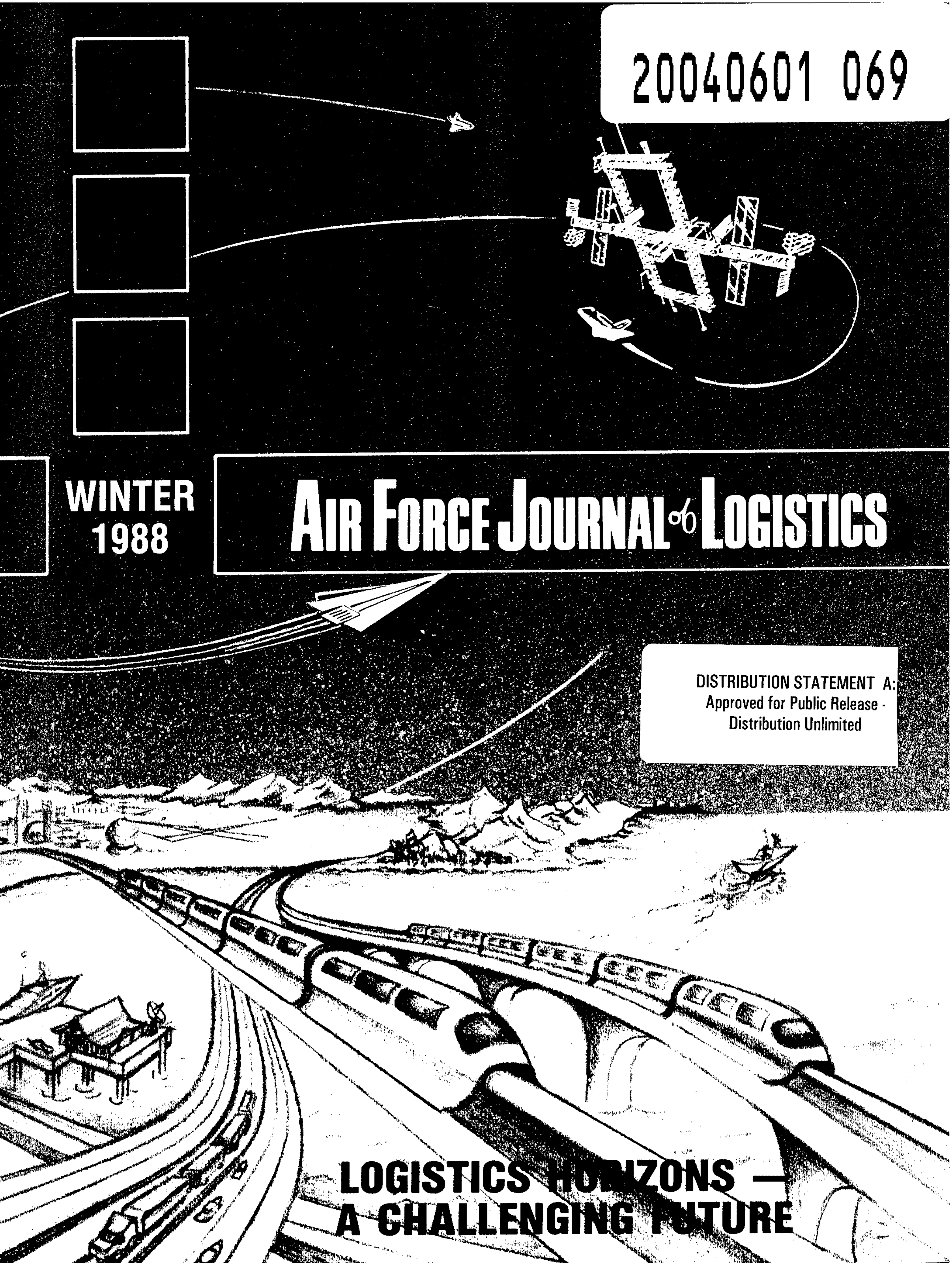

LOGISTICS HORIZONS — A CHALLENGING FUTURE

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CONTENTS

Purpose The *Air Force Journal of Logistics* provides an open forum for the presentation of issues, ideas, research, and information of concern to logisticians who plan, acquire, maintain, supply, transport, and provide supporting engineering and services for military aerospace forces. It is a non-directive, quarterly periodical published under AFR 5-1. Views expressed in the articles are those of the author and do not necessarily represent the established policy of the Department of Defense, the Department of the Air Force, the Air Force Logistics Management Center, or the organization where the author works.

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The Evolution of an Air Force Logistics Concept of Operations

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Providing combat support to our operational forces in a dynamic wartime environment will challenge the ingenuity of the logistician and stretch the peacetime logistics infrastructure beyond its maximum capacity. For the past few years, the Air Force logistics community has been struggling to develop and document basic concepts, values, and operating principles in an official doctrinal publication. The first step was accomplished with the publication of AFM 1-10, *Combat Support Doctrine,* which outlines the role of combat support, describes in very basic terms the process necessary to support combat operations, and prescribes those principles guiding the performance of combat support activities.

However, this was only the beginning. The next critical step is to provide the linkage between combat support doctrine and the plans, policies, and programs required to create and sustain combat capability. One of the key elements in establishing this linkage is development of an Air Force Logistics Concept of Operations and supporting theater logistics concepts of operations. These concepts will provide the direction and linkage between our combat support doctrine and strategic planning objectives. The strategic planning objectives will then provide the focus for policy and programmatic changes necessary to improve combat capability. Development of a logistics concept of operations has been under way for the past few years with many individuals contributing, both in and outside the Air Force, to a definition of how we should posture ourselves to support operations in wartime. However, several of these contributions were controversial and led to a lack of consensus among senior Air Force logisticians.

Air Force Tiger Team

It was primarily for this reason that Lieutenant General Leo Marquez, DCS/Logistics and Engineering, HQ USAF, chartered an Air Force Tiger Team at the Air Force Strategic Planning Conference (Future Look) in March 1987 to review all on-going efforts and develop an Air Force Logistics Concept of Operations upon which the corporate Air Force would agree. The Tiger Team included some of the most senior and experienced logisticians in the Air Force: the Deputy Director of Logistics Plans and Programs (Chairman), HQ USAF; senior Air Staff Logistics and Engineering (LE) and Plans and Operations (XO) representatives; assistant LGs from many of the MAJCOMs; and senior logistics representatives from the Air Force Logistics Command (AFLC).

The Tiger Team met for a week in June 1987 at the Air Force Logistics Management Center (AFLMC), Gunter AFS, Alabama, to develop an overarching Air Force Concept of Operations which would be the basis for subsequent development of theater concepts and Air Force and MAJCOM plans, policies, initiatives, and programmatic decisions to improve warfighting capability. During a week of intense deliberations, the Tiger Team studied work already accomplished in the logistics concept area; the wartime environment, both from a support and operations perspective; and deficiencies in the current logistics support system. The team then developed a list of areas to be included in the concept.

Wartime Environment and Deficiencies

In assessing the wartime environment, the Tiger Team concluded that, depending on the level of conflict and the theater, the Air Force will probably have to overcome high levels of combat attrition in both weapon systems and support infrastructure. Again, depending on the location and level of conflict, it will also have to assume vulnerability of fixed support locations. This could, in turn, necessitate mobility of the support structure. The team also concluded there will probably be high levels of consumption for individual items which will not be predictable at the base, or even theater level, and the industrial base will not be able to respond in any meaningful manner for a considerable period. Most importantly, they concluded there will be a great deal of uncertainty in many areas and the support system will have to compensate for this uncertainty. There will be unpredictable changes in operational requirements because of the flow of the war which will require changes in support planning and emphasis. Loss of support resources will require augmentation. In general, the war will not go exactly as planned, demanding a lot of flexibility in the support structure.

Major deficiencies in the support structure were:

(1) Shortfall and vulnerability of both strategic (inter-theater) and theater (intra-theater) transportation.

(2) Malpositioning of resources, especially items such as munitions and fuel.

(3) Late arrival of intermediate maintenance capability such as avionics intermediate shops (AIS) that could offset some of the uncertainty of demand for critical spares.

(4) A command, control, and communications system that is questionable because it is vulnerable and does not provide decision makers with the right information at the right time to make important resource allocation decisions.

(5) Delayed reaction of CONUS depots to wartime requirements and a system that assumes our vast depot complex will have only limited involvement in the first 30 days of a conflict.

(6) Overall vulnerability of the air base support structure and its ability to launch aircraft, defend itself, survive, and continue to prosecute the war.

Concept Assumptions

After looking at the environment and deficiencies in the logistics system, the Tiger Team concluded the logistics concept should include a number of key items and assumptions:

(1) Strive for maximum, but not necessarily total, self-sufficiency.

(2) Strive for flexibility through all levels of conflict for all theaters.

(3) Ensure the basic fighting unit is the squadron/base with its basic support structure.

(4) Deal with the reality of constrained resources.

(5) Provide flexibility to share resources in theater and even globally to meet the many uncertainties.

(6) Ensure theater/unit commander has control over resources (does not preclude reallocation of these resources to meet higher priorities).

(7) Apply to all classes of supply and levels of conflict.

(8) Make certain the combat support system is flexible enough to react to change and uncertainty.

(9) Recognize and plan for support to allies and other services.

(10) Accommodate damage to logistics resources.

(11) Energize the depot complex with its vast industrial capability at the beginning of a conflict.

(12) Provide a continuous flow of resources to combat units.

(13) Emphasize that combat support structure, policies, and procedures should respond directly to operational requirements.

AF Logistics Concept of Operations

The result of this intense investigation and analysis by the team is the framework for an Air Force Logistics Concept of Operations. The basic framework contains nine primary elements which provide the basis for individual theater concepts and is intended to respond directly to operational requirements, recognize the uncertainties of war, provide for maximum unit self-sufficiency, and operate in a resource constrained environment. The framework is designed to expand in detail as the various elements are refined by the MAJCOMs and the Air Force Staff.

Primary Elements

Command and Control

Command and control is the "steel thread" that must pass through and connect all logistics resources and activities. Effective command and control requires a clear recognition of the wartime organizational structure and identification of the real decision makers at all levels—strategic, theater, and unit. It must identify and provide minimum essential information and distribute the information in a timely manner so commanders or other decision makers at any level can make quick and accurate decisions regarding the allocation of resources within their area of responsibility.

Mutual Support

Mutual support is the element intended to strengthen the individual fighting unit by drawing upon resources from its own or another theater to satisfy shortfalls. While we recognize that unit self-sufficiency is needed and is a goal, especially during periods when external support may be disrupted or otherwise unavailable, support from outside sources will be required because total self-sufficiency is unrealistic except for short periods of time. In fact, the uncertainty associated with changing operational priorities and unknown support demands will necessitate resource reallocation to support these changes and to maintain and enhance a unit's self-sufficiency. The bottom line is that commanders at all levels must have the capability and authority to redirect resources such as spares, munitions, repair capability, and manpower to meet operational requirements.

Depot Support

Timely depot support is critical to maintaining unit readiness and should be fully used early in a conflict as an integral part of combat support. Our assumption was that depots will not get fully involved in the war until after day 30. However, to sustain warfighting forces, Air Force depots need to move towards a process that prioritizes the repair and distribution of resources as forecasted by operational requirements. This process must be structured to react effectively to unpredictable fluctuations in demands at the unit level as the flow of a conflict dictates. Early availability of depot support could not only lessen reliance on prepositioned material but also enhance the ability of a unit to remain self-sufficient and prosecute the war on its own.

Forward Support

Forward support provides the needed additional in-theater resources to support in-place and deployed forces. Forward support can take many forms depending upon the particular theater involved and the level and nature of the conflict. Flexibility and ingenuity in planning for forward support are vital.

It could, for instance, consist of maintaining a warm base at one or more rearward areas used to augment existing theater repair capability or push required depot support or critical resources forward to the theater. It could also provide for forward stockage points where resources could be staged and redirected by theater authorities to compensate for changing priorities. This support could include pushing depot support, such as depot repair teams or battle damage repair teams, to existing bases.

The intention is to get as much of the required support as possible to the theater where it is needed. Differing circumstances within each theater will, of course, dictate what is needed and what is possible.

Allied/Joint Support

This element requires the theaters to work logistics support actions with other services and allied nations. Plans and policies should be developed to ensure we have visibility over the support we will be giving and receiving from our allies and other services and that this support is integrated into our

overall planning efforts. It is essential that we not only understand the "where, when, and how" of both the support we will be expected to provide and the support we expect to receive, but that we also understand its impact on our overall combat support structure.

Inter-theater (Strategic) Transportation

Inter-theater transportation, both air and sea, is intended to provide a continuous flow of resources to the theater in accordance with essential priorities, taking into account the competing requirements of the different services within a particular theater. The theater CINC has the responsibility to prioritize allocated transportation.

It is incumbent upon the Air Force Logistics community to articulate transportation requirements accurately for resources such as spare parts in its input to theater war plans so movement of these resources can be properly prioritized against available transportation. This planning must also account for the movement of retrograde cargo from the theater to the CONUS, as well as to evaluate non-combatant evacuation requirements.

Intra-theater Transportation

Intra-theater transportation, whether by land, air, or sea, is intended for unit resupply and redistribution of assets under mutual support. This support comes from various sources, including the Air Force, allied nations, or other services. The volume, routing, and frequency of delivery are established by theater authorities and changed as necessary to meet operational requirements. Flexibility in the use of intra-theater transportation is essential, when combined with responsive command and control, to provide required flexible combat support. As with the other concept elements, the uniqueness of the theaters will dictate how intra-theater transportation is applied.

Mobility

Mobility of combat units to meet contingency operations is critical. We must plan for and be able to deploy the combat support necessary to meet wartime operational requirements. We must be able to push resources to the theater, when and where they are needed. These resources must be those required to launch combat sorties. Constraints of available transportation resources make it imperative that our mobility planning sends the right things to the right place at the right time. In addition, we must have the ability, using effective transportation and command and control systems, to redeploy parts of units, or whole units, as priorities or the combat situation dictates. The enemy's capability to disrupt our operational plans, or damage or destroy the support structure, may dictate temporary withdrawal from a base, reconstitution at another location, or reallocation of forces. Theater logistics concepts and combat support plans should be prepared to address these situations.

Air Base Operability

Air base operability is the cornerstone of the logistics concept of operations. Operability is the unit's ability to fight as an integral unit. It addresses the combat support structure's ability to enable the unit to launch sorties during and after attack, generate a robust massed force, maintain force effectiveness, defend the air base and its resources, and provide resources to prosecute the war. Although air base operability has been of concern for many years, senior management attention has recently focused on it through exercises and studies which specifically addressed our ability to fight the air base and recommended areas where improvement is needed. Of all the concept elements, air base operability is one of the most unique. How air base operability is achieved within a theater, within a region of a theater, or even between bases may be uniquely different. Roles of the MAJCOMs and the Air Staff are being carefully reviewed to ensure the right focus is provided to respond to these differences. While the overall direction and focus will certainly come from the Air Staff, it is the theater and unit commanders who, using the "tools and techniques" provided, must, in the end, determine how to achieve maximum base operability. The logistics community's role in this complex area is immense and, although a lot of work is being done, more is yet to be done at all levels.

In summary, the overarching Air Force Logistics Concept of Operations developed by the Tiger Team is a skeletal beginning for theater concept development. It in essence states that logistics support must be strongly linked to operational requirements. We should be organized to provide for centralized control at all levels and to the point required to maintain an optimal allocation of combat support resources. However, execution of that combat support should be decentralized to the lowest practical level. We should strive for maximum base self-sufficiency within known fiscal limitations and an uncertain environment during wartime. We must maintain the capability to augment units through a variety of means to compensate for uncertainty and to provide the flexibility to respond to changing operational requirements.

The keys to making this a reality and in the end providing for maximum base operability are both a responsive transportation system and a responsive and survivable command and control system that serve as the common thread that unifies the unit, theater, and strategic levels of command to produce maximum combat support (Figure 1).

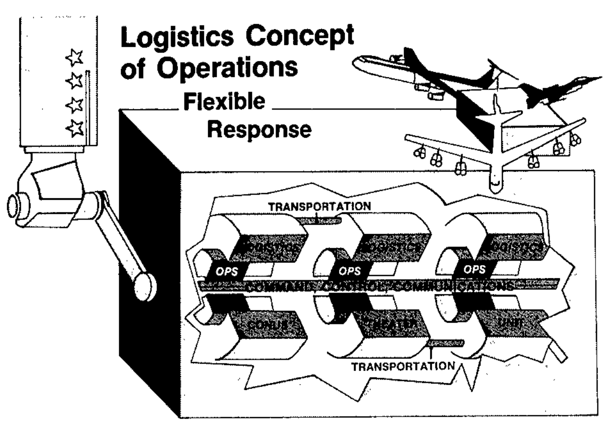

Figure 1.

Where Are We Going?

The question now is: What do we do with this generalized Air Force concept now that we have it? The challenge is to take this skeletal concept, develop it, and turn it into reality at the strategic, theater, and unit level. The Air Force Logistics Concept of Operations and the accompanying theater concepts

will provide the linkage between our Combat Support Doctrine as outlined in AFM 1-10 and our strategic planning objectives, policies, and programs.

We have begun the process of developing theater concepts within the MAJCOMs. At the Air Force Logistics Strategic Planning Conference at Charleston AFB, South Carolina, 3-5 November 1987, specific MAJCOMs shown in Figure 2 were assigned the task of developing theater concepts using the nine Air Force logistics concept elements as a foundation. Theater concepts are to provide a baseline of where we are today and a visionary look at where we should be in the twenty-first century.

THEATER	ASSIGNED MAJCOM
EUCOM	USAFE
PACOM	PACAF
CENTCOM	9th AF (TAC)
SOUTHCOM	12th AF (TAC)
NORAD	1st AF (TAC)
LANTCOM	TAC
JTF-ALASKA	AAC

Figure 2.

In parallel to these efforts, MAC was tasked to develop a concept for inter-theater transportation that crosses all theaters. AFLC is developing an overall depot support concept in addition to supporting the other MAJCOMs with their theater concepts. An Air Force Tiger Team, chaired by AF/LEXY with representatives from all MAJCOMs, is developing an Air Force Logistics Command and Control Concept of Operations.

The bottom line of this effort is to put some detail into the Air Force Logistics Concept of Operations and build theater concepts of operations that will provide the connection between doctrine and planning. More importantly, this will provide the focus for development of strategic planning objectives which will, in turn, provide direction for policy and programs that will allow us to provide the most combat capability with the available resources.

Conclusion

The evolution of the Air Force Logistics Concept of Operations and its accompanying theater logistics concepts of operations is in its infancy. These concepts will give the Air Force vital linkage between Air Force Combat Support Doctrine, which provides an overall perspective of what is involved in combat support and wartime logistics, and planning and programming. This is the critical step needed to turn the visions of leadership, which are contained in our doctrine and concepts, into the reality of an improved and balanced combat support system that provides maximum capability and flexibility to support operational requirements. Logistics leaders, at all levels, must examine what it takes to create and sustain combat capability, and use their vision, experience, and knowledge in developing the roadmap of where we want to go. Without the vision and without this roadmap, we severely limit our ability to do what we are here to do—produce combat capability to support combat operations. It is a difficult and complex task that is easily put aside because it is not a "today" problem. It is critical to our future, however, that we put it on the "front burner" and, as individual units, theaters, MAJCOMs, and, most importantly, as an Air Force, provide the vision to develop our roadmap for the future, through cohesive and meaningful doctrine, concepts, and strategic planning. This will, in turn, provide the solid foundation and focus for future policy and programs which will give the Air Force maximum combat capability with the resources available.

▶ Continued from 31

managers should thoroughly understand the JIT system and the cost accounting systems and concepts used by contractors to estimate and justify the prices to be paid. It is also essential to keep up with the evolution of cost accounting systems taking place in the future.

Notes

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[3] Greeley, Brendan. "General Electric Pleads Guilty to False Claims," *Aviation Week*, 20 May 1985, p. 27.

[4] "Defense Keeps Tightening the Screws on Contractors," *Business Week*, 2 February 1987, p. 34.

[5] Gregory, William. "Defense Increases Scrutiny of Contractor Costs," *Aviation Week*, 24 November 1986, pp. 64-67.

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[10] Hunt, Rick, Garrat, Linda, and Merz, Mike. "Direct Labor Cost not Always Relevant at H-P," *Management Accounting*, February 1985, pp. 58-62. See also Vivian Wright, "The Effect of Zero Inventories on Cost (Just-in-Time)," *Proceedings of Cost Accounting for the 90s: The Challenge of Technological Change*, National Association of Accountants, 1986, pp. 157-160.

[11] Ibid.

[12] Kim, et al, op cit, p. 15.

[13] Holbrook, W. "Practical Accounting Advice for Just-In-Time Production," *Journal of Accounting and EDP*, Fall 1985, pp. 42-47.

[14] Hilts, D. M. and Russell, G. W. "Accounting for the Factory of the Future," *Management Accounting*, April 1985, pp. 34-40. They observe that coupled with the decline of direct labor costs is the increase of factory overhead. The increase primarily involves the addition of highly paid professional and support staff (p. 38).

[15] Hunt, op cit.

[16] Schonberger, 1986, op cit, p. 177.

[17] Lee, John. *Managerial Accounting Changes for the 1990s*, McKay Business Systems, Artesia, California, 1987, p. 57.

[18] Schonberger, 1982, op cit, p. 27.

[19] Hunt, op cit.

Item of Interest

Pacific Distribution System Inaugurated

A new express parts delivery system, the Pacific Distribution System (PDS), was inaugurated at Kadena AB, Okinawa, in October 1987.

Under PDS, the Air Force is dedicating six C-12 aircraft to fly parts needed to restore weapon systems to full mission capability at bases in the Pacific. These cargo missions will be directed by the PACAF Logistics Support Center, Kadena AB, Okinawa, and flown by crews from the Military Airlift Command.

Reliability and Maintainability: Key to Combat Strength

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It was once observed: "Wars and economy are things not easily reconciled." Before World War II, if a nation was not at war, the economic pressures from military expenditures were not a matter of much concern. Since that great war, however, this nation has found itself in a position of world leadership—and with this position has come the requirement to maintain a large, standing armed force characterized by mission capable weapon systems with the technical sophistication to defend this nation and its vital interests.

So today, even during peacetime—especially with the kind of violent peace we are experiencing—we must be ready for war. But the cost of readiness makes it increasingly more difficult to reconcile military spending and the nation's economic well-being. With the planned 1988-1989 budget cuts, and the additional constraints posed by Gramm-Rudman-Hollings, the defense industry will be operating in a constrained resource environment. Unlike the past, there is no longer a "tooth fairy," and there will be no bailout at the eleventh hour.

We face a terrible dilemma. On the one hand, this nation must get a better handle on deficit spending; but on the other, it must provide for a strong and credible defense. Resources are on the decline, while the threat continues to grow—and nuclear arms control efforts put an even greater premium on maintaining conventional force capabilities.

We need to find better ways to provide a defense that can do the job, but at a price this nation can afford. Also, we need to find better ways to get the required combat capability from the available resources, thereby reducing the continually growing force structure and logistics requirements.

There is a practical solution to the problem—an effective way to have the force structure we need to fulfill our military commitments anywhere in the world, and at any time, and to save perhaps billions of dollars in the process. The solution is reliability and maintainability (R&M).

There is nothing really new about using R&M as a force multiplier. We have known the potential benefits for some time. In the early 1980s, Air Force Logistics Command (AFLC) even did a study on the cost of unreliability.* It presented some startling conclusions on how we spent defense dollars. For example, the study found that parts failures accounted for 75% of support equipment costs in aircraft procurement accounts and at least 20% of the Air Force budget. The study also showed that the impact of improving reliability was significant. In fact, for a composite of fighter aircraft, doubling the mean time between failure (MTBF) would reduce the spares requirement by some 80%.

Reducing spares requirements that much would make a tremendous difference in our ability to fly and fight—and would do much to redress our resource problem, especially in the longer term. In fact, assuming just a 5% inflation rate, we could save $1 trillion, 238 billion over a 30-year period. We have been accused of squandering a trillion dollars. What about the impact of saving a trillion dollars?

There were lots of reasons why we did not take full advantage of R&M years ago. For one thing, we were all products of a "use and replace" society. In the late 1970s, almost 85% of what the average American threw away on any particular day was not garbage—it was stuff which was broken and too much trouble or too expensive to fix.

A fundamental assumption underlying this mind-set is things break and unreliability is a fact of life we must accept. We learned to think that way because we grew up with unreliable technology. The assumption that machines have to break dated back to the Industrial Revolution, when technology was, of practical necessity, unreliable.

During the 1800s, we invented incandescent bulbs to light our way, pneumatic tires to carry heavy loads, and the telegraph to communicate rapidly over long distances. But bulbs burned out in a matter of hours, tires went flat on every other outing, and telegraph lines always seemed to be down. Today, we have sodium bulbs that burn for tens of thousands of hours, steel-belted tires that never seem to go flat, and redundant microwave and satellite systems which provide almost totally reliable communications.

We accepted unreliable systems in the past because we did not have the know-how to build better ones. In fact, back then, often just building them at all was a real accomplishment. Today, we do have the know-how to build them better and to make things that will not break—or at least not very often. We also have the means to design systems so that, when they do break, we can readily fix them. So no longer is there any need to put up with systems that are inherently unreliable or that cannot be readily maintained. The old dichotomy of performance versus reliability no longer exists.

The second reason we did not take full advantage of R&M was, quite frankly, we did not need to. As defense budgets increased in the early 1980s, the pressure to change outdated mind-sets was reduced. At the time, we could better accept trading off R&M in our weapon systems for other performance characteristics. We could simply deal with the inherent limitations of unreliable systems by throwing money at the problem and buying our way out—at least in the short term.

In addition, some people saw increased R&M as a threat to the established logistics support infrastructure—and not without some justification. The better a system's R&M, the less logistics it requires—and that means drying up workload for those who currently provide that support.

Today, however, as resources become more constrained, they will be less available to support unreliable systems. Certainly there will not be enough to support those systems and, at the same time, have the necessary mission capability.

*"Costs Associated with Item Failures," Headquarters AFLC/XRS, March 1984, unpublished.

In fact, today, R&M is perhaps the most effective way to decrease costs significantly and, at the same time, increase mission capability. Some workload may well dry up because of R&M, but it is workload we can no longer afford.

We have to remember our first responsibility is to meet the threat with logistically supportable weapon systems. After all, the Russians are not reducing their military spending to comply with Gramm-Rudman. It is our solemn obligation to give the citizens of this country every drop of combat capability possible for every tax dollar they invest—and if the Air Force wants more force structure in a declining budget era, R&M is the way to get it.

We know we can cash in on the leverage of R&M because we have already started to do so. Just consider the success story we have had with the F/FB-111 Avionics Modernization Program. Before the modernization effort, the Doppler Radar Set had an MTBF of 49 hours. In the upgrade, we asked for 750 hours MTBF, but got considerably more. In fact, after 2,000 flight hours, there were no failures or removals. Another subsystem was the inertial navigation unit. Before the upgrade, it had an MTBF of 19 hours. We asked for 525 hours MTBF in our modernization specs, but got 4,000 hours for this dual system. As you can see, these examples point out a deficiency in our level of expectation.

The trends are basically the same for all the avionics subsystems being modernized, whether the Attack Radar System or the Weapons Navigation Computer. The F-111 Avionics Modernization Program raised the overall avionics system MTBF from 3.9 hours to 25 hours, and we now have indications that the figure could well exceed 40 hours.

What that means for strategic forces is a twelvefold increase in reliability and a 29% increase in weapons delivery effectiveness. For tactical air forces, it means a 13% increase in sortie rates, and a 38% increase in expected kills.

We saw the same kind of payback in another R&M success story—the Central Air Data Computers. Under the old way of doing things, we had 19 different configurations with an average cost of $56,900. For the C-141 alone, we had a total peacetime and wartime requirement for 872 spares. With the new Standard Central Air Data Computer, we only have to deal with four configurations at an average cost of $31,900 per unit—and for the C-141, instead of 872 spares, we only need 187. The savings in spares costs for this one airplane amount to almost $44 million.

As mentioned, tightening resources means we have to save money and still maintain our combat effectiveness—R&M does both. However, to deal with the resource constraints ahead, we need to make success stories like the new Standard Central Air Data Computer happen throughout the Air Force. We need more cases where things do not cost as much, we do not need as many, and the encumbrance of logistics on our fighting forces is not as great.

Today, R&M represents far more than something which simply makes a lot of sense. In fact, given the budget crunch we are now in, and the kinds of national security requirements with which the Air Force must deal, R&M might well be our salvation. We already know what needs to be done, and we already know how to do it.

The shift in national priorities, along with a very dangerous world situation, is sending us a clear and unmistakable message—and injecting R&M into existing Air Force weapon systems should be the answer. That is where the biggest payoff is to be found, especially since these weapons will represent a majority of our force structure beyond the year 2000.

How do we go about doing that? What are the challenges, and what do we do to cope with them? In terms of challenge, a lot has changed in the past few years. Funding constraints now highlight the need for R&M, and the senior Air Force leadership actively embraces the concept.

In addition, the operational community once focused almost exclusively on "rubber on the ramp." The main concern was how high, how fast, and how far. Today, these same people are asking how long and at what logistics cost . . . and they are stopping programs when they get the wrong answers. In fact, today, the operators are perhaps the most vehement supporters of efforts like R&M 2000.

The challenge of dealing with the mind-set problem is being met. We are on the way to wiping out R&M illiteracy. Those who really count in the scheme of things no longer accept unreliable machines. In this regard, technology has grown up.

What we need to do now is better translate our attitudes into actions. In my mind, it is time to put our money where our mouth is by better incentivizing private industry to push the edge of the R&M envelope because private industry represents the real arsenal of democracy in this country. It is where military technology is developed, and it represents the most fertile ground for improving R&M.

How do we improve R&M incentives? Simple. Periods of scarce resources are not only times of great challenge—they can also be windows of substantial opportunity. The defense business environment will no doubt be tough and competitive—and we need to use these characteristics to our best advantage. We can emphasize doing business with those companies which have the best R&M track records, making R&M the key to corporate success with the contractors' market share proportional to the R&M of their products.

Furthermore, to better stimulate the creativity and "Yankee Ingenuity" for which American private industry is known, we should not use R&M specifications as goals in contracts. Instead, we should use them to establish baselines and to define the minimum acceptable level of R&M. Make the sky the limit. Those companies that climb the highest will be the ones who get the contracts and flourish; those who don't, won't.

Sir Francis Bacon once wrote: "It would be foolish to try to do things that have never been done except by means that have never been tried." The kind of R&M effort discussed has never been done. Some broad-scale R&M efforts have been tried before, and these have failed.

This time, however, we have three things working in our favor: the technological means we did not have before, a shifting of national priorities with attendant funding constraints, and operators and senior leaders who are now demanding R&M. I know that in AFLC, I have even gone so far as to establish a whole new approach to quality—one which will discipline basic processes to include such concerns as R&M. It is the first step toward institutionalizing R&M.

All in all, the bottom line is this: We in the business of national defense have the sacred obligation to do what it takes to provide for the security of this nation. We must recognize that things have changed, and the time is right for action. We must move out now to make reliability and maintainability the cornerstone of our overall quality effort to build the force structure needed. With a well-thought-out and disciplined requirements process, coupled with smart business strategies designed to incentivize R&M, I am confident we will do what needs to be done—because, in the final analysis, there really is not any other choice. AFJ

Combat Support Technology for the Twenty-First Century

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Introduction

Since publication of the 1982 study *Air Force 2000,* with its characterization of the future battlefield, many bold and different signals have become visible concerning the future Air Force fighter combat operational environment. The study focused on the inseparable involvement of the weapon-delivery platforms and their support structure in combat.

Enemy capabilities are increasing in terms of numbers and accuracy at an unprecedented rate. The result of this change is a challenge in which no aspect of the support structure can enjoy immunity from the harsh realities of combat. Consequently, General Dynamics/Fort Worth Division has intensified its independent research program, placing emphasis on application of technologies that will enhance combat support effectiveness for fighter weapon systems. This article presents the results of some of these technology investigations, projecting fighter aircraft combat maintenance into the next century.

Combat Support

As the twenty-first century nears, attitudes, thought processes, and actions must change in relation to the technology used for combat support. Combat support technology includes such things as diagnostics; maintenance aids; munitions interfaces and handling equipment; camouflage and concealment; servicing self-sufficiency; fuel storage and handling; and discretionary maintenance.

The entire operation and support environment must be considered. Such an approach makes it possible to identify and assess support and mobility impacts during the weapon system design process, making appropriate tradeoffs to optimize combat effectiveness by including combat support features.

Figure 1 shows that future-oriented designs must include capabilities structured to future requirements. We will identify some of the ways to enhance combat support technology and will cite the consequences of failing to do so.

Traditionally, the weapon system design process has focused primarily on the air vehicle's performance characteristics. Recently, the Air Force has placed much greater emphasis on enhanced combat support performance and combat support resource requirements. Ongoing efforts under the Air Force Reliability and Maintainability (R&M) 2000 Initiative by the Air Staff and the tactical air forces have identified clear goals, needs, and measures of attainment to be applied to fighter aircraft enhancement.

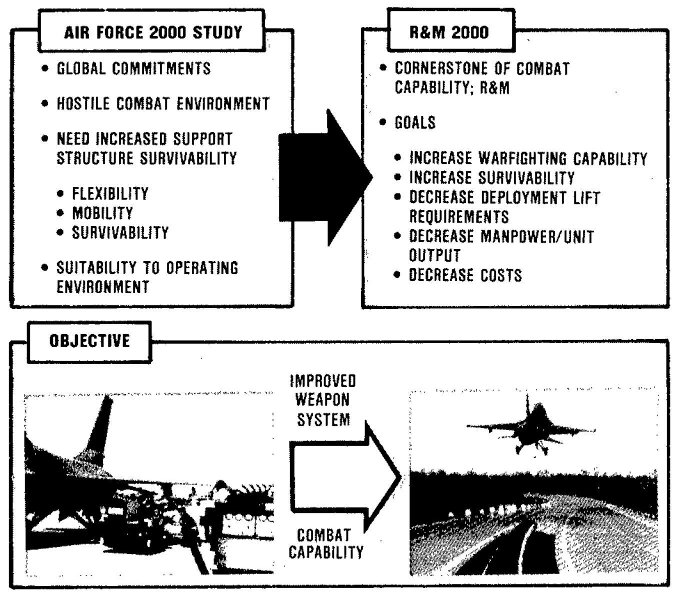

Figure 1: Designed Capabilities Structured to Requirements.

The emerging concept of computer-aided logistics (CALS) will also extend the traditional performance-oriented focus to accelerate identification of support equipment, training equipment, and other support resources during design. As CALS becomes more widely available to designers, they will have more rapid feedback on the consequences of their design choices.

Combat support technology for the twenty-first century must go beyond mere identification of the required combat support resources. It must also seek to either eliminate the need for these resources whenever possible or produce breakthroughs in their utility. For example, the use of on-board oxygen generating systems eliminates complex cryogenic production, handling, and storage tasks that complicate combat support and provide an inviting target during conflict. Furthermore, combat support technology can provide better ways to integrate munitions and associated equipment. Munitions-handling issues need to be addressed along with the weapon platform for enhanced operating flexibility. As a minimum, previously unforeseen maintenance problems must be predicted and eliminated during development and test in order to reduce the amount of unscheduled maintenance.

Many of the weapon systems that will be used early in the next century are in the inventory today (F-15 and F-16). Each will probably change significantly through updates during the next decade. Attention must be applied with rigor and enthusiasm to the enhancement of existing weapon systems as well as to future weapon system design requirements.

Change is required in the combat support aspect of the weapon system design process for many reasons:

- Changing threats
- Shrinking budgetary resources
- Demographic trends
- Operation and maintenance manning imbalance

Changing threats. The Soviets view combat as unending. Lenin stated that "peace is combat by other means." Besides, direct confrontation with the Soviets, other threatening sources of potential combat lie in the many low-intensity conflict situations around the world. These low-intensity situations can threaten United States interests at any time and require action by military forces. Soviet power in support of communist doctrine is widely dispersed and very capable. It includes a blue-water navy with access to warm-water ports in Cuba, Nicaragua, Lybia, and Viet Nam. The numbers of Soviet weapon-delivery platforms are increasing in air, land, and sea forces. Their levels of accuracy and sophistication are also growing. Tactical missiles that carry chemical, area-denial, anti-personnel submunitions are a threat to air bases. Soviet design emphasis and operational emphasis are illustrated by Figures 2 and 3. As a result of improved Soviet capabilities, it may be necessary to disperse less-than-full squadrons of fighter aircraft to austere deployed operating locations in order to survive on the ground.

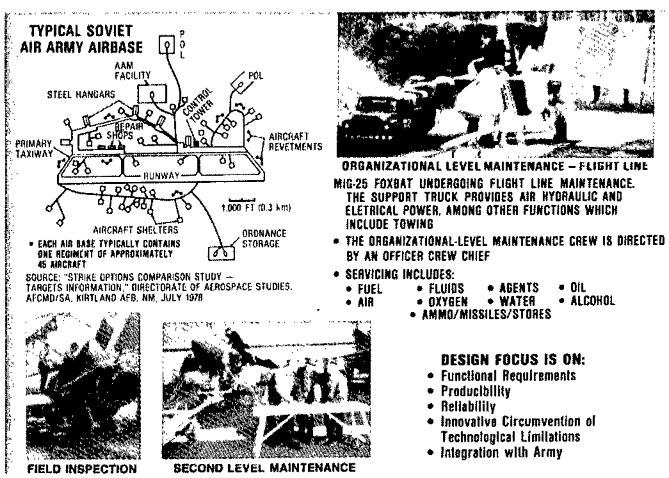

Figure 2: Soviet Design Emphasis - Simple Maintenance.

WARSAW PACT PRACTICES DISPERSED BASING USING MULTI-ROLE SUPPORT TRUCK

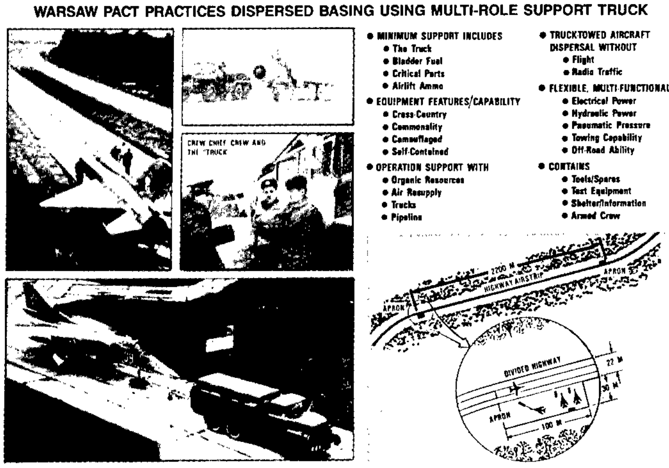

Figure 3: Soviet Operational Emphasis - Dispersal.

Shrinking budgetary resources. While the costs of new, sophisticated weapon systems are increasing, procurement budgets are decreasing. In the face of growing emphasis on fiscal responsibility, unprecedented federal and international trade deficits, and increasing threats posed by enemy technological advances, we must plan on upgrades to extend the life of existing weapon systems rather than relying exclusively on acquisition of new systems. Consequently, enhancement modifications and enduring technologies are going to receive more emphasis than in past decades.

Demographic trends. Demographics of the United States are changing with a resulting impact on the way the Air Force does business. Because of lower birth rates, fewer people are available in the prime recruiting age groups. Further, those youth who are available are able to choose from a wide range of similar and attractive opportunities in manufacturing, services industry, and military career areas. Also, the experience and mechanical skills, once developed by youth in American agriculture, are diminishing in the general population. On the other hand, computer skills are becoming more widespread. These demographic trends constitute serious considerations for designers of weapon systems and their combat support. NATO/Warsaw Pact demography trends to the year 2000 are projected in Figure 4.

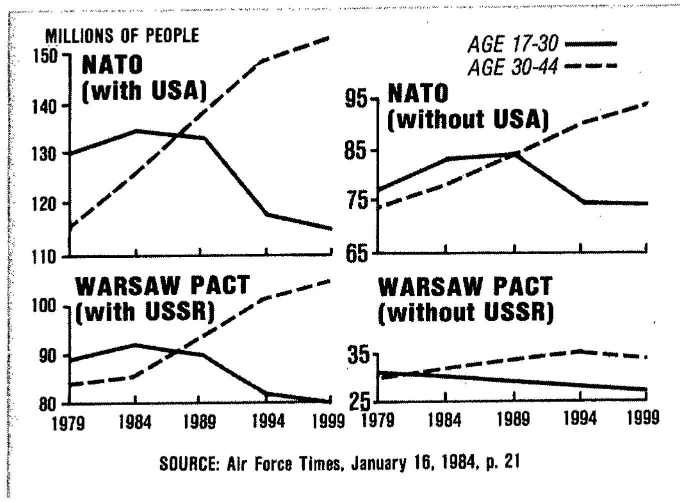

Figure 4: Demography of NATO/WARSAW Pact, 1979-99.

Operation and maintenance manning imbalance. Within congressional limits of Air Force manpower, an apparent imbalance is emerging between the operation and maintenance populations. Technologies are extending the numbers and hours of combat sorties a fighter can achieve. Current aircrew manning ratios appear to be insufficient to sustain the all-weather/all-hours combat sorties that can be generated in the foreseeable future by the maintenance community. By using technology, the amount of manpower required to service and maintain fighter aircraft in combat can be further reduced. The result will be more available manpower spaces to fly the additional combat sorties generated.

These major technology and threat changes occurring in the world around us have more impacts on weapon system designers. The impacts also extend to support of combat operations. Evolving fighter employment concepts emphasize the need to design for deployability and self-sufficiency as indicated in Figure 5. As contractors and the government address these changes, solutions to existing and emerging problems can be forged.

Acceptable support technology can be improved to enhance combat flexibility and military operating effectiveness in the twenty-first century. Following are some areas of interest with some suggestions as to how the solutions can be identified and

implemented:

- Acquisition incentives to reduce combat support requirements
- Diagnostic self-sufficiency
- Munitions and munitions-handling processes
- Interoperability and self-sufficiency
- Communication requirements

"Eighty-seven percent of our fighting forces would go as single squadrons to bases where there would be no other American squadrons deployed."

Air Force Magazine, Jun 84

MAJ. GEN. HOLMES, TAC DCS/LOGISTICS

"It doesn't do any good to have a superior airplane that can only fly once, if the enemy's got one that flies three times and is unopposed. To match the Soviet threat, we need to fly sortie after sortie, again and again."

Airman Magazine, May 86

GEN. ROBERT D. RUSS, TAC COMMANDER

HIGH PROBABILITIES	VIRTUAL CERTAINTIES
• ENEMY ATTACK ON THE BASE	• MOBILIZATION FOR DEPLOYMENT
• SUPPORT RESOURCE CASUALTIES	• AUSTERE ENVIRONMENT
• DISRUPTION OF "NORMAL PROCEDURES"	• NEED FOR SELF-SUFFICIENCY

Figure 5: Fighter Employment Concepts Designed for Deployability and Self-Sufficiency.

Acquisition incentives to reduce combat support requirements. Firm and realistic requirements, as opposed to such vague statements as "highly desirable," place clear emphasis on supportability. Firm requirements, which are achievable, cannot be misread, nor do they require interpretation or second-guessing of the customer's true intent. To cite an example of a vague requirement, a recent solicitation set a goal of manpower per aircraft, but it failed to define what was included or excluded in the requirement. Clear measures of merit are required in the contract and its predecessor documents to indicate the emphasis being given supportability. For example, measures of merit may be stated as maximum cargo airlift sorties required per 24 fighters deployed. Figure 6 illustrates the need to reduce cargo airlift for deploying fighter aircraft. Similar examples include manpower per aircraft or maintenance man-hours per flying hour. Limiting requirements to the maintenance picture can also be highlighted. Such criteria might be stated as support equipment maintenance personnel per squadron or munitions-maintenance manpower per thousand rounds. To reduce the ambiguity in the previously cited requirement, the government

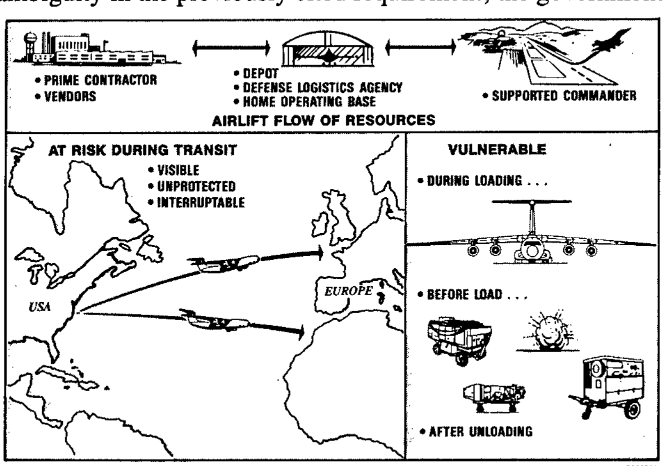

Figure 6: Cargo Airlift Requirements and Vulnerability Reduced.

could have specified that support equipment technicians and munitions storage and buildup personnel were excluded. With these considerations, government and industry will enjoy the benefit of firm goals that can be met, demonstrated, and rewarded.

Diagnostic self-sufficiency. Maintainability enhancement in the detection and isolation of faulty equipment can substantially improve maintenance productivity while reducing inventory costs. Some senior technicians characterize current diagnostics in the electronic arena as "swaptronics," meaning removing and replacing electronic units until the indicated deficiency appears to be corrected. Yet, with accurate diagnostics, today's problems of spurious failures, unneeded removals, and costly spare part inventories have the potential to be reduced substantially. Post-maintenance verification of corrective action can also reduce maintenance time through the use of built-in test features of the automated diagnostic routine. Meaningful measures are required which relate to diagnostic self-sufficiency. Judicious application of firm maintainability requirements can also enhance sortie production while providing opportunities for discretionary maintenance. Changing combat conditions place unprecedented emphasis on the need for fighter aircraft self-sufficiency in diagnostics and others support areas as indicated by Figure 7.

Munitions and munitions-handling processes. Today's labor-intensive munitions-handling and buildup tasks use up about 50% of the required cargo associated with fighter aircraft squadron deployment. Accurate measurement of current

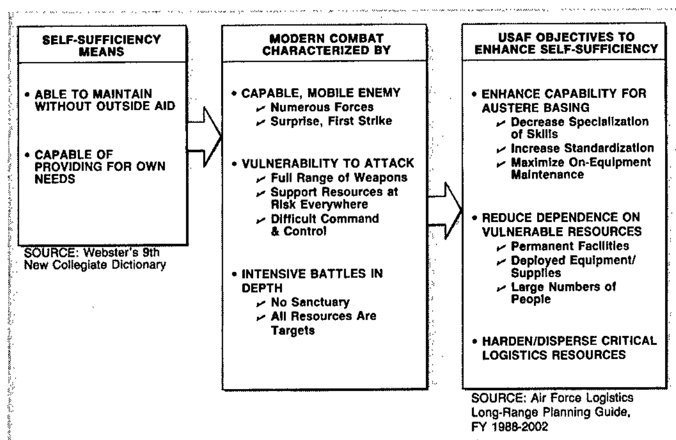

Figure 7: Changing Combat Conditions Place Unprecedented Emphasis on Self-Sufficiency of Fighter Aircraft.

requirements and a clarification of requirements language are appropriate steps to reduce the equipment and personnel per aircraft required to sustain deployed fighter operations. Associated benefits would be reduced vulnerability, increased operating flexibility, and reduced cargo-airlift costs. An example of an innovation to enhance munitions-loading productivity is a bomb-loading munitions "trailer" that eliminates the need for a bomb lift truck to perform intermediate munitions-handling tasks. The trailer fits under the weapon loading stations of the aircraft, allowing ordnance to be loaded directly onto the aircraft. Another area for examination and improvement is the complexity of weapons loading. These maintenance burdens and related handling certification training tasks could be addressed as design requirements for new munitions. The resulting benefits would be fewer flight-line support equipment units required, with an attendant reduction in ground vulnerability.

Interoperability and self-sufficiency. It is unlikely that a particular type of fighter aircraft will be isolated from other types. In fact, alternate recovery bases will probably be used to obtain cross-servicing. For example, an F-16 may be recovered at a NATO base and require servicing by Luftwaffe technicians. Such combat support activities are practiced daily. Interoperability between allies is essential to facilitate this cross-servicing cost effectively. Commonality of equipment and emphasis on aircraft independence of consumable gases and fluids enhance interoperability and self-sufficiency while reducing the combat support tether that ties aircraft to their bases. The resulting benefit from innovation in this area of combat support is greater operating flexibility over a wider range of basing and employment conditions.

Intrabase communications. Daily operations rely heavily on communications. In combat, support-related communications traffic increases dramatically. In the continuing resource-limited environment of fiscal austerity and multiple global commitments, communications are essential to sustaining fighter aircraft. And, today, communications that relate to reporting and to ordering combat support resources are vulnerable and ponderous at best. Clogged data transmission facilities can be avoided by designing systems that are more reliable, more redundant, and more self-sufficient—systems which use fewer spares and no exotic, consumable resources. Further, burst-transmission techniques for remaining ground resources, along with such techniques as a push system of supply and accurate inventory tracking in the deployed operating locations, are approaches that could minimize the amount of communications needed for support in forward areas.

The foregoing issues of change and challenge must be addressed for new weapon systems and for enhancement modifications to existing weapon systems entering the twenty-first century inventory if these systems are to be survivable and sustainable. The multitudes of employment environments are forecasted to be increasingly demanding. If adequate attention by government and industry is not given to all support issues, the hostile threat and environment could overwhelm the capabilities of technologically superior weapons.

Consequences of failing to enhance effectiveness and to reduce the need for combat support for fighter aircraft are inevitable and unacceptable to this nation and the free world. Among the possible consequences are:

- Increased vulnerability to enemy ground attack
- Operating inflexibility
- Lack of self-sufficiency
- Increased operating costs
- Dependency on cargo lift (air or surface)
- Inability to sustain combat operations

Recommendations

Today's weapon system support problems can be effectively addressed in several ways. Many solutions are now in place. Others are emerging. In conclusion, let us consider three general recommendations that are particularly important:

(1) *A systems-engineering perspective is required.* A stewardship beyond narrow responsibility exists and must be met by both industry and government. "For engineers . . . the one true road must pass through effectiveness and creativity, and the ideal starting place is conscientiousness," according to Samuel Florman in *The Civilized Engineer*. This means abandonment of narrow parochial attitudes and being able to identify, throughout the development process, with the full range of combat-employment environments which the weapon system may encounter in its lifetime. A systems-engineering perspective might properly include the elements presented in Figure 8.

(2) *All persons involved in the acquisition process must recognize the impacts of their decisions on both combat use and related support.* This begins with the government statement of need (SON), which tends to bound military weapon system design alternatives. Past customer demand for weapon-delivery-platform support alone is not successful. In future acquisitions, requirements must encompass the entire weapon system—including all interfacing support systems, ground threats, and vulnerability analyses, as is being done with emerging advanced fighters.

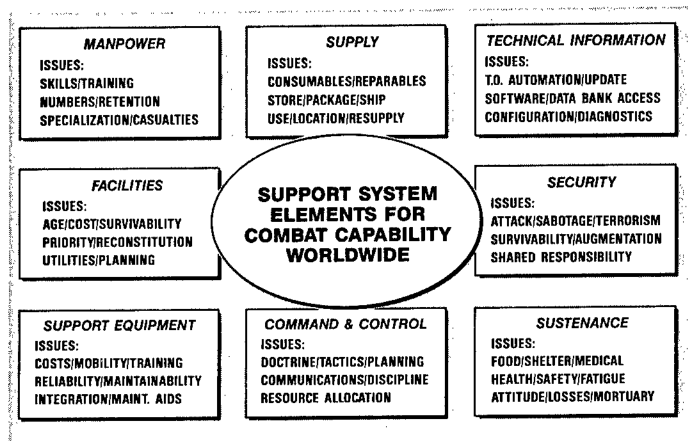

Figure 8: Systems-Engineering Perspective Required.

(3) *Government and industry must foster open communications.* Contractors must have ready access to and interest in all aspects of existing weapon system support information, both before and after a contract is awarded. In addition to knowing how the Air Force flies, contractors must be given the opportunity to understand peacetime and combat doctrine, regulations, and basing. Industry must understand more than just mission-performance criteria. Government personnel and publications are another excellent source of such information. Blue Two visits for industry are an excellent beginning to building a bridge of understanding between industry and the Air Force customer supporting weapon systems. From this understanding, contractor engineers and product support personnel can effectively focus industry's attention on the important support-related issues. Closely related is the effective application of independent research and development monies and other related efforts which will give insight and focus to the government's support needs. With this increased understanding, knowledge, research, and cooperation, combat support will continue to improve. We *can* meet the challenge of the twenty-first century.

The original version of this article first appeared in the 22nd Annual Proceedings of the Society of Logistics Engineers.

Air University Logistics Research in the PME Classes

The logistics related research papers and projects completed by the students of Air War College and Air Command and Staff College during the 1986-1987 academic year are:

Air War College

"An Analysis of Air Force Pacific Theater Contract Maintenance and Its Effect on Combat Capability"—Lt Colonel Stanley A. Sieg **(WINNER—Society of Logistics Engineers (SOLE) Logistics Award).**

"Reform and the Air Force Military Construction Program"—Colonel Donald J. Thomas **(RUNNER-UP—Society of Logistics Engineers (SOLE) Logistics Award).**

"In Search of Command and Staff Doctrine"—Colonel John R. Brancato.

"Developing a Unified Command Plan"—Colonel Harry E. Colestock III.

"Combat Sustainability and Reconstitution Warfare: The Missing Link in Air Force Basic Doctrine"—Colonel Orville M. Collins.

"In Pursuit of Leadership—the Prescriptive Approach"—Colonel Dale O. Condit.

"Electronic Warfare in Vietnam: Did We Learn Our Lessons?"—Colonel John R. Dickson.

"A Strategy for Space Warfare"—Colonel Alfred R. Garcia, Jr.

"Coping with Terrorism"—Colonel John E. Killeen and Colonel Robert A. Hoffman.

"Changing the Western Alliance in the South Pacific"—Wing Commander Brian L. Kavanagh, RAAF.

"Civil Engineering Combat Support: Are we Ready? Have We Learned?"—Colonel Edward M. Smith.

"Planning for Theater Warfare Using the Concept of Massive Air Strike to Insure Success"—Brigadier General Abdel Hamid Sorour, Egyptian Air Force.

Air Command and Staff College

"Electrostatic Discharge"—Captain James F. Diehl **(WINNER—Air Force Logistics Management Center Logistics Research Award).**

"Universal Numbering Structure for Weapon System Support"—Major Michael G. Anderson **(RUNNER-UP—Air Force Logistics Management Center Logistics Research Award).**

"Computer Software for Life Cycle Cost"—Major Richard E. Bowman.

"Contractor's Guide to Air Force Base-Level Contracting"—Major Edwynn L. Burckle.

"Air Force Acquisition: How Are We Doing?—Major Patrick J. T. Corrigan.

"Assessing the Resource Needs of Conventional Munitions Loading"—Major Aaron R. DeWispelare.

"United States Air Force Policy for Operational Test and Evaluation"—Major W. Keith Everly.

"Microcomputer CADD and the Air Force Civil Engineer"—Major Neil H. Fravel.

"Logistics and Engineering 101, The Primer for Base Level Logistics and Engineering Officers"—Major Dennis C. Hughes and Scott L. Smith.

"The Defense Acquisition Process: A Current Assessment"—Major John D. Hutchinson.

"Wartime Base Supply Planning Guidance"—Major Charles S. Johnson.

"Benefits of Subassembly Competition for Production Contracts"—Major Steven R. Jones.

"The ABCs of the PPBS - An Action Officer's Glossary"—Daniel J. Mumaugh.

"Tactical Aircraft Refueling in USAFE: Mobile vs Fixed Systems"—Major David T. Nakayama.

"Reception Guide for Overseas Transportation Squadron Commanders"—Major John W. Pruitt.

"Project Turnkey: Historical Perspectives and Future Applications"—Major Jeffrey L. Tyley.

"Integrating the Tactical Air Power System to Improve Combat Capability"—Captain Robert M. Wallett.

"An Engineering Paraprofessional Workforce for Space—There is a Better Way"—Major John E. Wheeler.

"Aircraft Maintenance Quality Assurance Inspector AFSC"—Major Robert L. White.

Loan copies are available through the Air University Library, Interlibrary Loan Service (AUL/LDEX), Maxwell AFB, Alabama 36112-5564. Additional information on the ACSC studies can be obtained through ACSC/EDCC, Maxwell AFB, Alabama 36112-5542 (AUTOVON 875-2867; Commercial (205) 293-2867).

Most Significant Article Award

The Editorial Advisory Board has selected "Project RELOOK: The Case for Base Self-Sufficiency" by Lieutenant Colonel Thomas C. Nettles, USAF, as the most significant article in the Fall issue of the *Air Force Journal of Logistics*.

Best Article Written by a Junior Officer

The Executive Board of the Society of Logistics Engineers (SOLE) Chapter, Montgomery, Alabama, has selected "Meeting USAF Civil Engineering Customer Expectations" (Fall 1987 issue), written by Captain Max E. Kirschbaum, USAF, as the best *AFJL* article written by a junior officer for FY87.

The Emerging Environment of Military Logistics

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Introduction

This paper explains the results of an investigation that looked at transportation and distribution in the United States during the next 50 years and extends those results by examining some possible impacts and effects on military logistics. The study looked at (1) technologies that are primary drivers of transportation and distribution, (2) predictions of experts and/or futurists, (3) results of a survey of current, working logistics practitioners, and (4) past predictions made in the 1920s, 1930s, and 1940s about transportation and distribution in the 1980s. This was used to assess the potential accuracy of the current prognosticators. Each of these individual investigations is described in the box on page 13.

Transportation

There was substantial agreement from all information gleaned from all phases of this study that the changes occurring during the next 50 years in transportation will be evolutionary rather than revolutionary. This should provide some comfort to those who are disquieted by the thought of opening the door on 1 January 2001, the beginning of the twenty-first century, and finding a bright new world. History has shown that no matter how fast the environment is changing, there will always be a large tail of the old environment along with the new. This will be true in transportation despite the potentials already being engendered by such breakthroughs as non-cryonic superconductors.

> ***"Several technological events are occurring now that will have significant influence on transportation into the twenty-first century."***

Several technological events are occurring now that will have significant influence on transportation into the twenty-first century. For the most part, these affect all modes somewhat similarly. In the area of power plants, all types of transport will see the weight-to-power ratio decrease. More power for a given weight or equal power at less weight will lead to larger percentages of gross vehicle weight devoted to payload or faster transport for the same costs. Most modes will opt for a combination of the two. This offers some interesting possibilities in terms of the movement of personnel and cargo to forward areas and their necessary resupply. The ability to deliver more and do it in less time will enhance reaction time and improve our response to crisis situations anywhere in the world.

Perhaps the most exciting development that will affect all modes lies in the area of materials. Clark and Flemings stated:

> A fundamental reversal in the relationship between human beings and materials is taking place. Its economic consequences are likely to be profound. Historically humans have adapted such materials as stone, wood, clay, vegetable fiber and animal tissue to economic uses. The smelting of metals and the production of glass represented a refinement in this relationship. Yet it is only recently that advances in the theoretical understanding of the structure of physical and biological matter, in experimental technique and in processing technology have made it possible to start with a need and then develop a material to meet it, atom by atom. (3)

The quote suggests safer, lighter, stronger, and ultimately cheaper transport vehicles for all modes. In 1965 Lee Iacocca gave a speech about what the car would be like in 20 years. He said the car will have four wheels, be a thousand pounds lighter, carry a sophisticated version of the internal combustion engine, and will not carry a spare tire. He was wrong about the spare tire. Except for the failure to include the wholesale introduction of computer technology into the automobile, he says he would give that same speech today. (2)

Transportation vehicles of the next 50 years will be sleeker, be nearly maintenance free, carry sophisticated navigation and communication equipment, get much better fuel mileage, and be governed in almost all aspects by computerized components. However, beyond these generalities, there will be significant changes that differentiate the modes from what they are today.

> ***"A national rail system will emerge in the twenty-first century—this system will employ magnetic levitation."***

Private Carriage. Information gathered from all sources suggests that the major change that will take place in the personal transport system enjoyed by most Americans will be massive congestion. Los Angeles-style traffic conditions will afflict most populated areas of the country. The reasoning behind this prediction is based on the expected number of cars that will be sold in future decades and the lack of concomitant expansion and repair of highways on which to drive these machines. This, in turn, should increase the development and production of some type of ground effect machine (GEM) which can travel over badly pitted surfaces. Such a development is projected to lead to a specialized highway system that will have some lanes reserved for commercial use. The breakdown of the personal transport system will likely lead to a move for more regulation, and of course it will have an impact on the movement of military items over the road.

Motor/Rail Carriage. There was near consensus regarding some aspects of motor and rail transport. The breakdown of the personal transport system by congestion will also seriously impact the motor and rail systems enough to require more government intervention in the form of regulation. There was

INDEPENDENT INVESTIGATIONS

Technology Futures

Current structure, equipment, and practice of military logistics are but reflections of the technological changes that have occurred in earlier periods. From the very beginning, technology has paced the development of transportation and distribution. Key have been materials, manufacturing processes, energy or power sources, and control systems. The horse-drawn wagon of the 1700s was but an extension of the Roman chariot, a larger body placed on the chariot's standard axle gauge. (This standard gauge was four feet, eight and one-half inches.) In the 1800s the newly-developed system engine replaced the horse, and the rail replaced the steering reins and the road. The result was called the locomotive or Ironhorse. The gauge was still and today remains four feet, eight and one-half inches. Better chassis, better power sources, better control, and better construction methods are the history of transportation and, in good measure, distribution. This study examined hundreds of current data bases for information relating to these dimensions. These bases were primarily technical libraries of both industry and the academic world. A few of these searches yielded information that significantly addressed transportation or distribution. For example, the October 1986 edition of *Scientific American* contained an article entitled "Materials for Ground Transportation." The March 1987 edition of the same magazine had an article, "Optical Neural Computers." Both of these works describe technologies that will have a decided effect on the future transportation and distribution systems of the twenty-first century, but only one of them is specifically associated with these areas. This was the general case; however, it was not a major impediment to the study. In most cases it was not difficult to make an extension from a described technology to transportation and distribution.

Futurists' Views

The term "futurists" as used in this study refers simply to those many and varied individuals who are expert or visionary enough to write about the future. The futurists for the basic study come mainly from the ranks of academia, though there were several editors, freelance writers, and even an occasional science fiction writer.

All the works (books, articles, essays, news releases, etc.) investigated in the course of this research came from the California State University Library located on the campus in Sacramento. This 820,000 volume resource was more than adequate to cover the area investigated. A library search for works dating from the present back to no more than 1979 limited the scope of the search but ensured the currency of the material. The card catalog was searched for titles indicating some relevance to transportation and/or distribution in the future. For example, a work entitled *Shape of Wings to Come* was clearly germane to the study as it addressed both the future and the air transportation mode. All selected works were published by legitimate publishing houses, but no attempt was made to evaluate the credentials of the writer.

The analytical technique employed for this study was tabularization. A work was read. Its major themes, conclusions, and/or findings were first tallied and later tabulated by category. Categories with greater than five entries were considered significant for this study. No statistical analysis or enumeration was employed.

Survey

It was felt that a survey of practitioners must be an integral and essential part of any attempt to discern the future configurations of the logistics systems of the twenty-first century. Practitioners work with these systems daily. Many innovations and changes that are only now beginning to influence logistics will be the normal way of doing business in the future. While the general public and non-practitioners would be unaware of these emerging changes and their potential importance, practitioners have the experience and knowledge to assess their effects and potentials properly.

For this study, an open-ended survey questionnaire was sent to 125 people occupying high-level positions in logistics organizations scattered across the United States. All potential respondents were either members of the Society of Logistics Engineers or the Council of Logistics Management. The specific composition of the selected individuals is shown in Table 1. It is perhaps significant to note that many of the respondents currently employed either as consultants or private sector executives are military retirees including several flag rank officers with extensive logistics command experience.

Distribution of Practitioners Surveyed

Industry Classification	Private Sector	DOD	Public USA	Sector USAF	USN
Air	9			4	1
Rail	13		1		
Truck	10		1		
Water	4				2
Pipeline	11			1	
Users	37			6	2
Dist & Whse	9	1			
Auxiliaries	4				
Consultants	9				
Totals (125)	106	1	2	11	5

Table 1.

The purpose of this study was not to gain specific information that could be tested in any kind of a statistical sense, but to simply determine the inherent feelings of today's logistics practitioners. If any type of consensus emerged, so much the better.

This element of the total study was extremely helpful in aiding our efforts to project some predictions into the unique military logistics environment. Individual comments from study respondents are used to describe some anticipated changes in areas of military logistics. This aspect lends credence to the forecasted environment of future military logistics.

The Past

Before any investigatory work began on any part of this study, a decision was made *a priori* to include a section that would look back and see how well past futurists had done in terms of forecast accuracy. In the course of the investigation for this section, the following was encountered:

> Before one attempts to set up in business as a prophet, it is instructive to see what success others have made of this dangerous occupation—and it is even more instructive to see where they have failed. (1)

Because this study arbitrarily decided to look into the future approximately 50 years, the starting point for the PAST investigation was also fixed at approximately 50 years ago or the 1930s. However, the 1930s were a unique period in American history. The depression overshadowed almost all other concerns during a large part of the decade. In order to avoid the bias that might be caused by this national catastrophe, the period of selection was extended to include a wider span of years. Of the 98 works investigated for this phase, the breakdown by decade is:

<1920s	1920s	1930s	1940s
6	34	52	6

The sources examined for this study were diverse. They included professional journals (30%), business magazines (17%), popular magazines (29%), trade journals (15%), and the press (8%). Examples of titles for each of these categories are: *Annals of the American Academy*, *Business Week*, *Popular Mechanics*, *Aviation*, and *The Wall Street Journal*. The authors included: subject matter experts (39%), scholars (25%), editors (14%), and freelance/anonymous (22%).

great belief that a national rail system will emerge in the twenty-first century. Many suggested that this system will employ magnetic levitation. Recent breakthroughs in non-cryonic superconductors support the feasibility of this occurrence. Several writers also saw a sort of merging of trucks and trains into a mini-train system that would roll on pneumatic tires, guided by cement roadways dedicated to such use. Most predictors saw but a few railroad systems in the United States by the year 2038. Those that are left will be true transportation companies, serving users with all forms of transport and transport support services. Supercarriers operating in all modes will be the rule. These transportation companies will develop into global organizations in response to varied transportation strategies being used by multinational corporations which are growing increasingly important in world trade.

The rapid progress being made in the telecommunications area will find its way into the transportation systems of the next 50 years. Ordering, billing, shipment preparation, dispatching, tracking, receiving, notification, storing, accounting, and a host of other functions using supersmart, artificial intelligence-driven computerized systems will be the norm in the transportation company of the future. Air Force Logistics Command is already in the process of developing expert systems for route scheduling and as a hazardous materials shipping advisor. These systems will result in a more efficient and effective use of transportation resources across the modes.

Losing an order or shipment, sending the wrong item, billing incorrectly, routing erroneously, or documenting improperly will be rare events, though they will occur. (Some things never change!) Reassuring, though, is that except for the manufacturing processes involved or the workings of the technology employed, each and every transportation and distribution practitioner will recognize the systems of 2038. Styles and appearances will surely be different than those of today, but a train will still be recognizable as a train.

"Growing interdependence will make us more and more dependent on overseas sources for both initial items and resupply."

Airline Operations—Passengers. The airplane or flying vehicle will still be the predominant passenger carrier for international and intercity travel. For the passenger this will mean faster, cheaper, safer, and more reliable travel. For the aircraft manufacturer and operator it means adoption of all those new technologies described: high technology manufacturing, communications, design, control, and power. Due to speeds, air control will be much more rigorous than today. Regulation will be the rule rather than the exception.

In the next five decades, air travel will take the ordinary passenger from the ground to space stations. These space stations will be used as production facilities because they offer zero gravity and certain atmospheric advantages in the production of key materials with military applications. Though the craft for this will not be the same as the one used for intercity travel, it will be but a more advanced design. With every city pair in the world no more than two flight hours apart, the way business is conducted will change, despite fantastic capabilities in telecommunications. The US government recently announced the award of three concept development contracts of $25 million each for an aircraft capable of 17,000 mph that would fly from New York to Tokyo in the aforementioned two-hour time frame. The propulsion system for this vehicle already exists. The problem is designing an air frame with materials capable of withstanding the stress of that speed at an affordable cost. The implication for military airlift and its ability to deploy and resupply overseas forces quickly is impressive. Reaction times will be cut to a fraction of their present estimates.

Airline Operations—Cargo. Air freight will continue to accommodate primarily high-value or highly perishable goods. The bulk of products shipped by all modes will continue to be extracted or agricultural commodities unsuitable and unable to bear the cost of air transportation. Air cargoes will be shipped on passenger runs. Air transport technology, especially power plants, will enable many small air/ground ports to exist economically close to production sites. Survey respondents saw the new manufacturing technologies and type of high technology products we are moving towards as a spur to the growth of air cargo volume because of their high value, low weight, low volume characteristics. Many of the barriers to international economic interchange (customs, tariffs, immigrations, regional restrictions) will be decreasing as world trade increases and we move toward more global economic integration. The trends are there already as the United States shifts more and more into a service and knowledge based economy. At the same time, Japan, South Korea, and Taiwan begin the move beyond mass production technologies. Their place in the manufacturing sphere is being taken by newly developing nations like Thailand and the Philippines. This growing interdependence and lessening self-sufficiency could assume tremendous significance for military logistics. It will make us more and more dependent on overseas sources for both initial items and resupply. This lengthening of the supply line, coupled with the loss of US capability in basic manufacturing industries, creates a new set of potential problems for military logistics planners in terms of control and possible interdiction.

Water Carriage. Most of the world's tonnage of commodities will still travel by water. The better materials, manufacturing processes, power sources, and control systems will produce far superior vessels to those of today in terms of efficiency, speed, and reliability. However, it is altogether likely that two new forms of water carriage will be common by 2038. These are the ground effect machine and the submersible. GEMs, which are presently used for special purpose carriage, could fill many niches where cargoes presently are shipped alternately over land and water for relatively short distances. Economics will still dictate some other form of water carriage for bulk commodities over long distances.

Submersibles are ships with little or no superstructure above the water's surface. We call most of our present-day submersibles submarines. There is no reason why cargoes or passengers cannot be carried in submersibles, either self-powered or towed. In fact, many predict they will be. Submersibles will reduce the air resistance of ships to practically zero. These ships will be less affected by ocean weather and wave action. For liquid commodities, submersibles might be made from flexible materials that could be folded up and flown or otherwise transported to their next onloading port. Some also suggest that submersibles will travel under ocean ice to shorten water routes.

Pipelines. The pipelines of the year 2038 will still look like pipelines and operate like pipelines. But, just like all the other modes, pipeline technology continues to advance. The same technological enhancements that will affect the other modes will also invade pipelines. Better materials will reduce pipeline life-cycle costs. These include rifling and lining. These techniques will further reduce the energy requirements for pipelining. Solids pipelining, one of the world's best-kept secrets, will also play a major role in the transportation system of the twenty-first century. Large volumes of solids mixed with a liquid will transport huge tonnages over vast distances at extremely low costs. To some extent this might help to decrease the problems associated with highway congestion mentioned earlier. Coal slurries are but a precursor of what will be shipped; however, right-of-way costs and environment concerns could impact the development.

In existing oil lines other, immiscible fluids will also be transported. Because these fluids will not naturally mix with the host fluids, they can be sent over vast distances without the need of segregation and count. In such cases, fluids whose shipments could not support elaborate pipeline systems of their own will enjoy the benefits of the host.

A slightly different version of the liquid pipeline has been suggested by several investigators as an obvious solution to some of the anticipated transportation problems of the twenty-first century. This is the pneumatic tube. Much like the pneumatic tube one uses at a drive-in bank to cash a check or make a payment, this system could relieve the tremendous pressure that motor carriage places on a city in the delivery of less-than-truckload shipments. Located some distance from the central business district (CBD), a single pneumatic tube delivery system (PTDS) could receive less-than-truckload shipments and distribute them to all business locations in the CBD via pneumatic tubes. Each L-T-L shipment would be placed in a pneumatic container or widget and whisked to its destination. There was little agreement on who would or should own such a system, and perhaps more importantly how the significant capital required to finance its construction would be raised.

Distribution

Overall there was much less information that addressed distribution per se in the next century than transportation. This was not surprising. Distribution is a concept, a collection, and a collage. Still, if one looks at the functions of a conventional marketing channel, one sees many changes that must occur in the next 50 years. (6) The functions that were considered for this study were design, make, brand/price, promote, stock, and display.

"The way products will be made and repaired in the twenty-first century will likely have the most profound influence on military logistics."

Design. Computer-assisted design (CAD) or an advanced derivative of it will be the norm in the future. Of special importance to the distributor is the fact that distribution will and must be an input in the design process. A product will be fully integrated at the design stage with each of the other elements of the distribution channel. No longer will a new product be designed that cannot be economically shelved near complementary items nor will products be designed that can neither be serviced nor supported. This latter aspect is of significant concern to military logisticians and has historically been a continuing problem.

Make/Repair. Of all the functions performed in the distribution channel, the way products will be made and repaired in the twenty-first century will likely have the most profound influence on military logistics. By the year 2038 nearly half of all consumer goods will be produced on-site, at the marketplace. Computer-assisted design coupled with computer-assisted manufacture and robotics will allow the ultimate user to describe a desired product in the convenience of a local facility and have the product produced nearly instantaneously, custom tailored and designed, on-site. The need for large-scale production facilities for many goods will evaporate. Economies of scale from large-scale production will be more than offset by savings in the reduction of industrial overhead with flexible manufacturing systems. The nature of the materials that the transportation system will carry will shift from finished goods to raw materials or semimanufactured items (5). This development should have a significant impact on levels of maintenance within the military services. The ability will then exist to place far more capability at organizational rather than depot level and negate the need to centralize many maintenance functions existing today. That would have the dual advantages of dispersal and faster, more responsive maintenance support in the field.

Brand/Price. Brand names will slowly yield to material and method-of-manufacture as the most common way of specifying products. Artificial intelligence, flexible manufacturing systems, and the widespread accessibility of technical information will dictate the way a large portion of consumer and industrial goods must be produced. For these goods, price will also be foreordained.

Promote. The advent of the local, flexible manufacturing system will greatly alter the promotion of goods and services. An ad for a dress boutique of 2038 will list the process to be employed, the source of raw materials, and the designers to which that shop subscribes. A list of customers both satisfied and dissatisfied will be available to the prospective new buyer. For the dress shop example, the future is already here (5). This capability coupled with CAD offers a unique potential to take a standard item, adjust the design, and tailor it to a specific requirement. Obviously this assumes the database has been purchased and is available. Just imagine the flexibility this would provide military maintenance and supply functions, particularly if this could be used at the organizational level.

Both this and the price aspect discussed should simplify the federal procurement process in terms of standard and replenishment items. For example, it should permit greater use of off-the-shelf commercial items to replace items with unique government developed specifications that can drive up acquisition cost. This push to functional specifications and commercial items was one of the thrusts behind the Competition in Contracting Act of 1984, and has been a congressional concern historically.

Stock. Reliability and consistency in the transportation area and on-site manufacturing of consumer goods will combine to drive stocking of inventory to extremely low levels. Just-in-time inventory systems will become the norm. This will force inventory risk back up the distribution channel to the manufacturers; however, technology will save them from maintaining large inventories. The interlocking of computer

systems between the supplier and the purchaser will allow faster, more efficient servicing of requirements. Errors will be low, stockouts rare, and customer satisfaction high. Supercomputers and other information processing advances will make the fully automated warehouse a standard fixture. All such warehouses will be able to communicate with each other without paper flow.

This, coupled with the increasing use of robotics, will reduce the labor-intensive nature of both the military and civilian warehousing function. The area will also be affected by the use of artificial intelligence and expert systems to duplicate the military inventory manager's decision process in making stockage, spares, and repair decisions. The development of these systems is currently in its infancy in the military.

Display. Everything that can conceivably be for sale will be able to be viewed via some form of electronic or optical medium. At home, at work, or at play, the poor consumer will be bombarded by "product information." Many of us with access to cable television have already experienced the beginnings of this merchandising revolution. The positive side of this aspect of distribution is that the customer will have an objective way to weigh various offerings as the average home will be tied to an information base. The average customer will stand a better chance of breaking even. This aspect will also affect the base procurement interface with the supplier in terms of purchasing standard items.

Reflections on Accuracy

Each and every prediction reflects a thought or position promulgated by several futurists, whether practitioner, prognosticator, or professional technician. But, how good are these predictors? In an attempt to answer how much credence one might place on such predictions, this study also looked back to see how well previous predictors of 50 years ago fared.

Analysis of the 98 PAST sources described covering four temporal divisions clearly suggests that prediction accuracy is closely related to the projected time period and the "cultural mood" of the population at the time. From the 1920s we have this example of a futurist assessing the total number of automobiles of the future in the United States:

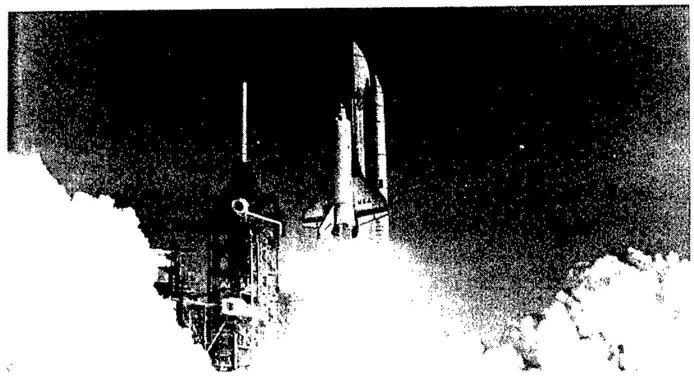
> Forty-four out of each one hundred persons are under twenty-one years of age, and four in each one hundred are over sixty-five years old. This leaves fifty-two percent of the people from whom the buyers must come. Seventeen percent of the fifty-two percent are either foreigners or colored people, and these classes are very seldom purchasers. This leaves thirty-five percent native-born white men and women of from twenty-one to sixty-five years of age. But the women are, in the main, the wives of men. Out of a total population of 105,000,000 this leaves about 19,000,000 persons to whom cars may be sold. (4)

Not only are the writer's biases and prejudices apparent in this forecast, but the culture comes through strongly as well. This was true of most predictions. It is also most likely true of our present-day futurists.

Analysis of past prognostications indicates that predictors were much better at assessing the impact of technology on the future than they were of changes in the political, economic, and sociological arenas. A brief look at the predictions of our futurists indicates the same shortcoming. For example, in predicting gridlock for most American cities in the twenty-first century, there is an assumption that the population will put up with this condition. And there is an assumption that the majority of people will welcome any new, superior technology and adopt it. History teaches us otherwise. This recognition was brought out clearly by one futurist writing in 1940:

> . . . the railroads will drop most of the long-haul passenger trains, for who will want to travel long distances at sixty to seventy or even 100 miles an hour on the ground when they can go from 300 to 1,000 miles an hour in the air—except some of us old-fashioned people of 1941. (7)

The predictors of 50 years ago writing about the 1980s and 1990s were extremely accurate regarding the technological aspects of transportation and distribution when taken as a group. There is little reason to suspect that those writing of the next 50 years are any less accurate.



Conclusion

What you have just read is a composite picture of a possible logistics environment that could develop over the next 50 years. Many of these things will come to pass, some will not, and others not currently imagined may be the norm. The primary point is that change will take place and in the view of the majority of experts, futurists, and survey respondents it will be evolutionary in nature. The one thing that the review of earlier futurists forecasting our present proved is that the forecaster is always a prisoner of his/her own time and this limits the accuracy of the predictions; however, much of what was forecasted has come to pass. There is little reason to suspect that those writing of the next 50 years will be any less accurate. The detail may err, but the general skeleton should be close to that projected.

In terms of military logistics, the emerging environment will offer unique opportunities to better support requirements. Many changes will be forced upon the current system and the way we now do business. Some of that change has already begun. You as practitioners and users of that system can read your own implications into the article and see those opportunities. As the future unfolds, you will help make it. What the system becomes in many cases will be influenced by your actions and decisions. Use the opportunity well and stretch the limits. The accuracy of the forecast is really in your hands—for the future begins tomorrow.

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A Support Concept for Space-Based SDI Assets

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On 23 March 1983, President Reagan announced the establishment of the Strategic Defense Initiative (SDI) research program. Since then, significant progress has been made in defining a strategic defense system (SDS). Concepts have been developed during the "horserace" architecture studies, system program offices have been established, and the first phase of the SDS is preparing to enter the demonstration/validation stage of system acquisition. As a result of these efforts, the sheer number of proposed SDS constellations has revealed the need for innovative methods of logistics support. Equally important has been the realization that operations and support (O&S) costs will likely be a large percentage of SDS life-cycle cost. A modest SDS baseline system of directed and kinetic energy weapons and sensors will cost many billions of dollars to support, based on current concepts. At this juncture, the mandate is clear: either reduce life-cycle costs or an effective SDS will not be affordable.

"On-orbit logistics support could significantly reduce the O&S portion of the SDS life-cycle cost."

On-orbit logistics support for space-based SDS elements could significantly reduce the O&S portion of the SDS life-cycle cost while maintaining high operational availability.

The exact number and location of SDI space-based weapons and sensors depend on the specific SDS element[1] concept selected. However, the baseline architecture for the mid-1990s and beyond includes boost and space surveillance and tracking systems, kinetic energy, and directed energy weapons.[2] Typically, these systems are grouped into constellations of like assets in medium- to high-inclination orbits (up to 90°) and at altitudes ranging from low earth orbit (LEO) to geosynchronous orbit (GEO). To keep life-cycle costs manageable, an orbit life of 10 to 20 years will be required for space-based SDS assets. This service life is a significant increase compared to that of previous spacecraft. Furthermore, the complexity and quantity of space-based SDS assets are significantly greater than all previously conceived or designed space systems. Additionally, SDS elements must be kept on alert status, ready to respond at a moment's notice to an enemy attack. Table 1 shows a range of potential annual failures for the elements of a typical or representative SDS. Even for elements with high reliability, there will be a significant demand for support to maintain a high SDS operational availability. The challenge is to develop a support concept that is responsive to SDS needs, capable of accomplishing logistics tasks in a difficult environment, cost effective, and flexible enough to accommodate different aspects of diverse SDS architectures.

ANNUAL FAILURE PREDICTIONS

ARCHITECTURE			ANNUAL FAILURES			
				Annual Failure Rate		
Asset	Quantity	Altitude	Asset	1%	5%	10%
SBI	1000	LEO	SBI	10	50	100
DEW	100	LEO	DEW	1	5	10
BSTS	8	Classified	BSTS	1	1	1
SSTS	20	LEO	SSTS	1	1	2

NOTE: Numbers Representative of "Typical" SDI Architecture.

SBI = Space-Based Interceptor
DEW = Directed Energy Weapon
BSTS = Boost Surveillance and Tracking System
SSTS = Space Surveillance and Tracking System

Table 1.

Concept Development

In developing a support concept for space-based SDS elements, two major alternatives must be explored: no physical on-orbit support and "hands-on" on-orbit support. No physical on-orbit support is the way satellites are currently maintained. Satellites are designed to achieve as long a life as possible and often incorporate highly redundant systems and subsystems. When anomalies are detected, telemetry-based repairs can be accomplished by switching in redundant systems or by software manipulation. Completely failed satellites are replaced with new satellites; therefore, spares stocking must be performed at the whole satellite level. Operationally ready satellites must be available in a ground-based supply pipeline for timely launch and orbital insertion, or they must be prepositioned as space-based spares. These spares could then be maneuvered into position to replace the failed satellites.

Preliminary research indicates the "no hands-on" maintenance option is costly, especially with increasing numbers of spacecraft; but all aspects of life-cycle cost must be evaluated before rendering such a judgment. In the past, the "no hands-on" maintenance option has been cost effective for some types of relatively low-cost satellites.[3]

"Hands-on" on-orbit support may be either scheduled or unscheduled, ground based or space based, and manned or unmanned (robotic). Scheduled maintenance activities include preventive maintenance actions and servicing to replace satellite consumables. Unscheduled actions involve maintenance on demand and would be in response to system failures. Space-based activities would be centered around a space-based support platform (SBSP) using other associated servicing equipment stationed at the SBSP. For ground-based actions, this support equipment would be kept on the ground and launched into orbit for each use. The question of manned versus unmanned maintenance and servicing is driven by two factors: the environmental risks involved in manned missions and determination of the most efficient and effective method to

perform functions on orbit. Most of the SDS satellites are expected to be in locations where currently available crew radiation shielding systems severely limit the period of time in which a manned mission can be exposed to the radiation environment, thereby restricting performance. It must be noted, too, that man-rated systems entail the additional cost and weight of the life support systems which must be carried into orbit.[4]

Of the three on-orbit support options (unmanned, space-based support; unmanned, ground-launched support; and manned, ground-launched support) primary emphasis has been placed on unmanned, space-based support. This emphasis has evolved from a careful evaluation of the location and distribution of SDS satellites, the cost of maintenance versus satellite replacement, the use of man in space, the on-orbit support options, and the types of on-orbit support missions. For some SDS elements, satellite replacement may still be the optimum support concept due to the cost and accessibility factors. In any case, on-orbit maintenance and servicing are clearly dependent on the characteristics of the individual elements and should only be applied where operationally and fiscally feasible.

There are numerous advantages to be accrued from performing on-orbit maintenance and servicing. On-orbit maintenance activities can replace failed components (black boxes known as orbital replacement units (ORUs)) to return a satellite to operational status. Replenishment of expended spacecraft consumables (fuels, coolants, batteries) can also return an otherwise healthy but nonfunctional spacecraft to operational status. In either case, the useful on-orbit mission life of the satellite will be extended. Space-based logistics operations can also provide timely response to system failures, helping the SDS maintain a high operational availability. In many cases, on-orbit maintenance and servicing are also the more cost-effective maintenance concepts. The initial cost of developing and deploying a space-based support architecture is more than offset by the savings resulting from the ability to provide spares at the component or ORU level rather than at the satellite level. Further, the cost per pound to place a payload in orbit is significant (currently about $3,000 to $4,000 per pound). Providing spares at the component level instead of the satellite level results in less weight to orbit over an element's lifetime, further reducing life-cycle costs.[5]

On-orbit maintenance and servicing also provide two additional benefits: First, this method is the only way to reconstitute a satellite after it has expended weapons and consumables during a test or exercise. Second, on-orbit maintenance can be an effective way of keeping the SDS responsive to evolving enemy threats by incorporating preplanned product improvements (P^{3}I) to the system at the satellite itself. For example, as technology evolves, a new data processing package or a new sensor suite may be installed on an orbiting satellite. System capability has been upgraded without having to replace an entire satellite or constellation. System effectiveness has been improved while holding down life-cycle cost. Again, the intuitive benefits of on-orbit maintenance and servicing appear significant, but each element must be examined on an individual basis to quantify the benefits.

Central to the space-based maintenance and servicing concept is a support architecture, the space asset support system (SASS), which includes space-based support platforms (SBSPs), orbital maneuvering vehicles (OMVs), orbital transfer vehicles (OTVs), robotic servicers, and fuel or coolant transfer vehicles. These elements are shown in Figure 1. The SBSP is the center of the on-orbit support activities. Based at low earth orbit in approximately the same inclination as the constellation it supports, the SBSP will act as a supply point to store ORUs and consumables for SDS satellites and other servicing elements. The SBSP could be automated using organic telerobotic elements for handling supplies and performing platform-associated support functions. The SBSP will provide a docking and storage facility for the other support elements (OMVs, robotic servicers) and will also act as a secondary maintenance facility to perform servicing on the servicing elements themselves. As with most nonexpendable spacecraft, the SBSP and associated support equipment will require specific maintenance or servicing over a projected 20-year life cycle. The SBSP would be resupplied by periodic visits from unmanned cargo vehicles (UCVs).[6]

The OMV is a kind of space tug used to transport the fuel transfer vehicles and robotic servicers with spare ORUs between the SBSP and SDS satellites. The OMV's range is limited to several hundred miles with a robotic servicer payload, and an OTV would be used if longer-range support missions were required. The robotic servicer will contain cameras, storage racks for spare and failed ORUs, as well as the robotic system itself. It should be operated either autonomously (using preprogrammed actions) or in a telerobotic mode with a ground-based operator. Fuel transfer vehicles would store, transport, and transfer liquid consumables such as hydrazine fuel, cryogenic sensor coolants, or laser fuels. These vehicles will be transported by the OMV (and perhaps integrated with a robotic servicer) and be capable of automated coupling with the SDS satellite's fuel coupler.

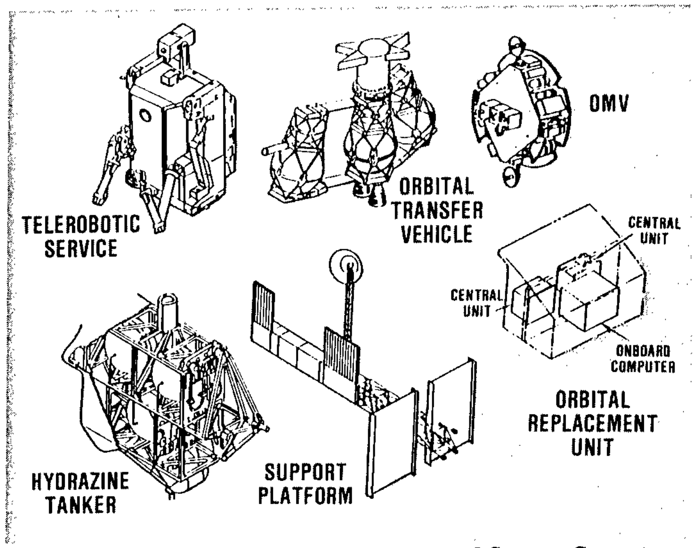


Figure 1: Six Elements of the Initial Integrated Support Concept for SDI Assets.

To minimize fuel costs involved with the routine maintenance and servicing activities, this support concept uses the normal regression of the line-of-nodes of an SDS asset's orbital plane with respect to the Earth's axis of rotation. The nodal regression rate is a function of altitude and orbital inclination. Placement of the SBSP in the same orbital inclination, but at a lower (or higher) altitude than an SDS constellation, produces a differential nodal regression rate between the orbital plane of the SBSP and the plane of the SDS assets. This causes the planes to align periodically, providing

opportunities to perform maintenance and servicing missions. The OMV would employ a minimum energy in-plane Hohmann orbital transfer to reach the SDS asset. Depending on phasing time, the time of flight (one way) for a Hohmann transfer with an OMV is approximately 1 hour. Routine servicing operations are estimated to require less than 12 hours, for a total mission duration of approximately 14 hours.[7] Figure 2 gives a pictorial representation of this concept.

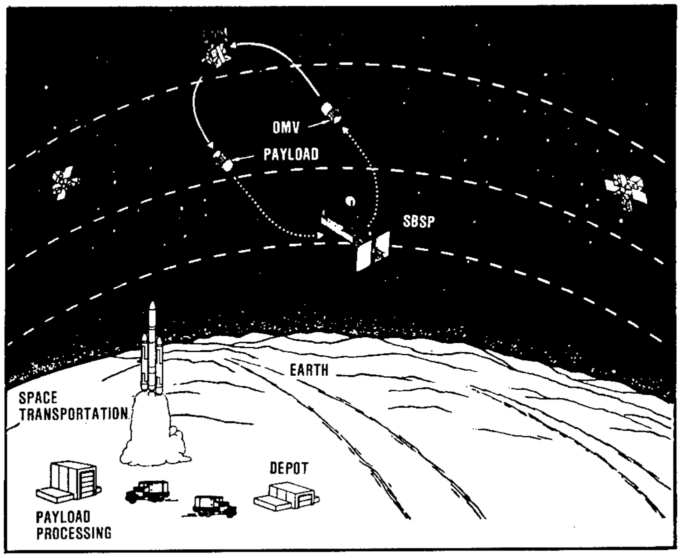


Figure 2: Initial Integrated Support Approach.

Each SBSP will be the base for at least two OMVs. This will provide for OMV-to-OMV servicing, permit both routine servicing and contingency maintenance operations to occur during periods of alignment, and avoid a single-point failure mode (the OMV) within the space-based support architecture. An OMV is currently being designed by TRW under contract to NASA, and current OMV design performance capabilities are consistent with this SDS support concept.[8]

The precise number of SBSPs required to maintain an SDS constellation must be optimized based on certain mission parameters. For instance, depending on the altitude, inclination, and number of rings in a constellation, a single SBSP will only have a certain window when it is in alignment with a given orbital ring in order to perform maintenance missions. Increasing the number of SBSPs and spacing them at equal intervals will increase the windows of opportunity to conduct maintenance. Ultimately, if response time to a failure becomes the paramount consideration, a concept of coplanar SBSPs and SDS satellites would be required. Here, an SBSP and associated servicing equipment would be placed in each ring of SDS satellites supported. Response time would be short, but space-based serving equipment would be proliferated, and the total weight to orbit would be significantly increased, particularly for large constellations like SBI. Studies will have to be performed to trade increased O&S cost of more architecture versus desired response time to any given failure within the SDS constellation. In this way, the size of the support architecture can be optimized to give the best balance of life cycle cost, supportability, and operational availability.[9]

While the emphasis of this SDI support concept has been on robotic space-based activities, there may be certain instances where manned or robotic missions launched from the ground may be required. In these missions, the servicing architecture must be inserted directly into the orbit of the failed asset. These missions may be required to respond to failures of high-priority assets which cannot afford to wait for alignment with an SBSP. Perhaps certain high-value systems will be deployed in a highly distributed manner. These constellations may require so many different sets of space-based servicing equipment that it would be uneconomical to maintain them from space. Finally, there may be some cases where manned missions are required. These will be very high-priority missions which justify the risk and where a human's discretionary and tactile capabilities are essential.[10]

A maintenance control center will be required to operate the space asset support system. Its functions include coordinating with the SDS satellite operators to schedule and plan on-orbit support operations; monitoring or controlling the telerobotic servicer during on-orbit support operations (such as servicing or resupply missions); manifesting SBSP resupply missions; and controlling the ground-based flow of parts, materials, and ORUs from manufacturers, storage facilities, or repair and refurbishment facilities to the launch sites. To improve survivability and mission effectiveness, more than one ground-based maintenance control center may be required.

Finally, the exact balance of performing periodic servicing versus maintenance on demand must be determined. For all failures, attempts to repair via telemetry will always be the first course of action. If telemetry repairs fail, a judgment must be made to determine how to proceed. In some cases, correction of anomalies can be performed in conjunction with a periodic servicing mission. In other cases, the nature of the failure, the priority of the asset, and the system operational availability will require an immediate response to correct a failure.

On-Orbit Support Functions

Now that a framework has been established for providing support on orbit, we need a more detailed examination of the kinds of logistics tasks to be performed. On-orbit support consists of a number of related operations:[11]

Replenishment: This task involves the on-orbit replacement of spacecraft consumables such as fuels, laser reactants, sensor coolants, and batteries. Included in this diverse category are hydrazine, N_2O_4, LOX, liquid hydrogen, liquid helium, cold nitrogen and helium gas, and nitrogen trifluride. This eclectic array of substances presents a variety of technological problems to be solved regarding on-orbit storage, handling, and transfer due to unique physical properties in a zero-gravity environment. Replenishment can be accomplished in two ways: First, consumables can be replaced by ORU or module exchange as might be the case for batteries or modular fuel tanks. Second, consumables can be replenished by direct transfer from a tanker vehicle to the SDS satellite.

"Replenishment of expended spacecraft consumables can return an otherwise healthy but nonfunctional spacecraft to operational status."

Replacement: Replacement is a task primarily concerned with the removal and replacement of ORUs in the event of malfunctions or the need for scheduled maintenance. Because

ORUs will be found on virtually all SDS assets (including the logistics support elements), replacement activity will perhaps be the most frequent maintenance activity performed next to refueling. Replacement activities might include the removal and replacement of cryo-coolers at the end of their life expectancy (periodic maintenance), or the removal and replacement of failed communications or sensor ORUs (repair action in response to an unscheduled failure). Replacement actions can be ideally suited (depending on satellite design) to accomplishment by a telerobotic servicer carried by an OMV or OTV.

Inspection: High-resolution, stereoscopic video cameras with illumination components on OMVs or servicers can be used to inspect SDS satellites. This activity will include examination of spacecraft structure for damage, inspection of electrical and fuel interface connectors, and investigation of assorted anomalous platform malfunctions. Routine automatic inspection modes could be programmed into the on-orbit servicer's activity schedule.

Calibration: Certain components on SDS satellites (possibly including navigational, communications, and sensor) may require periodic fine-tuning during their life cycle. This could involve the use of sophisticated test equipment and sensitive robotic end effectors if this task would be accomplished in-place via telerobotics. Calibration will be the most sensitive and difficult servicing task to accomplish on orbit.

Adjustment/Alignment: As opposed to calibration, adjustment and alignment involve repositioning or moving equipment, external mounts, and structural components of SDS satellites. For example, an antenna boom needing to be repositioned and a solar panel needing rotation are examples in this category. Nominally, the degree of sensitivity involved in adjustment and alignment is not as high as is required for calibration.

Assembly: Second-phase SDS architectures are likely to include assets that will require on-orbit assembly because they are so large that they cannot be launched into orbit in one piece, either due to volume or weight constraints of the launch vehicle. Directed energy weapons are but one example of an SDS satellite that may have to be assembled on orbit.

Requirements

However, before this support concept can be applied, several key requirements must be met. First, the cultural attitude that the current method of supporting satellites ("business as usual") is the only way to support the SDS must be overcome so the support architecture will be funded and developed. Also, space transportation (most likely expendable launch vehicles) must be planned not only to deploy the SDS, but the SASS as well. And, finally, two critical areas which must be addressed are satellite design and logistics technologies. If a satellite is to be supported on orbit, this must be considered from the outset of system design and will drive certain requirements in that design. To begin with, the satellites must be designed in a modular fashion with their functions partitioned into ORUs, and these ORUs must be accessible to a robotic servicer. This is contrary to the current design of most spacecraft. The OMV and the Hubble Space Telescope are notable exceptions, although the ORUs on the Hubble Space Telescope were designed to be removed by man.[12] Figure 3 is an exploded view of the OMV, showing its ORUs. Satellites must also be designed and built with a high degree of standardization and commonality. Standardization must include ORUs from satellite to satellite, interfaces within the satellite, and interfaces between the satellite and the servicing equipment. This will be essential to minimize the quantity of spare ORUs at the SBSP. Lastly, accurate diagnostics will be critical to an effective on-orbit support concept. Because of size and weight limitations on orbit, it will not be practical to carry complex diagnostic equipment with the OMV and robotic servicer. Similar constraints also mandate a high degree of assurance that the OMV/robotic servicer is carrying the correct spare ORUs when it goes on a maintenance mission. For these reasons, SDS satellites will have to incorporate a high degree of built-in test capability.

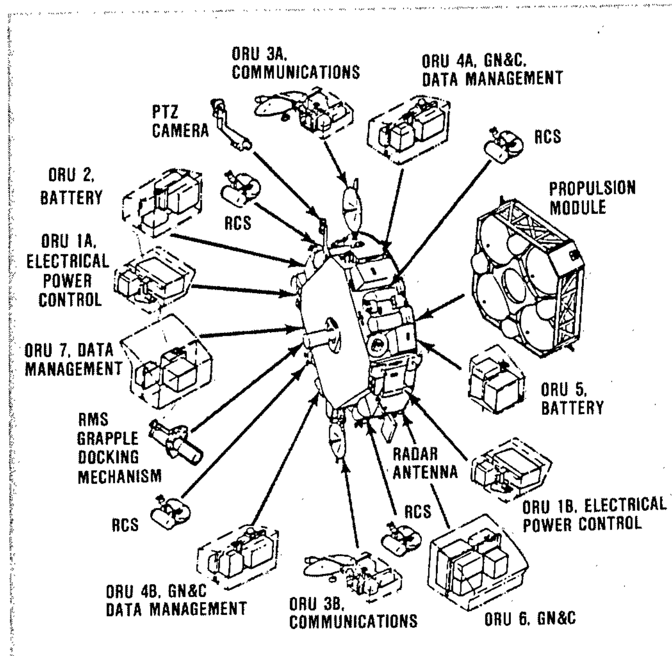


Figure 3: Fully Modular Design and Orbital Replacement Units (ORUs) Enable On-Orbit Maintenance.

Logistics Technologies

To accomplish the complex variety of support functions on orbit described earlier, a host of unique challenges must be overcome to work in the space environment. New logistics technologies must be developed or focused. Three of the most critical technologies involve robotic servicing; ORU design, storage and transfer; and fluid storage and transfer.[13] On-orbit assembly and support of SDS satellites will be extremely difficult to perform by extravehicular activity (EVA) methods because of the intense radiation present in the orbits of the proposed SDS architectures. The development of robotic servicing is the logical solution to this problem. The current state of the art (for all but the most simple tasks) limits robotic servicing to teleoperation which keeps man in the loop as an operator in a safe environment, controlling a telerobot some distance away. As telerobotics technology develops, it should evolve into more autonomous modes of operation such as supervision of individual telerobots and the monitoring of gangs of telerobots. Key areas of this technology which must be developed include sensing and perception, end effectors, operator interface, system architecture and integration, and time delays in the data link.

As noted before, a critical element to performing on-orbit support involves satellite design. The key to this is to have

satellites composed of ORUs which are designed to be stored and transferred on-orbit with telerobotic devices. This design must include thermal control (thermally self-sufficient ORUs for on-orbit storage), built-in test for fault diagnostics, fault tolerance (for "soft" failures) and redundancy management, hardening requirements, and maintainability considerations such as sure-fit electrical connectors and grappling attachment points. A key technological challenge will be to incorporate these requirements while minimizing weight and volume impacts to the ORUs and the overall satellite.

One way of extending satellite lifespan is to replace essential liquids such as cryogens, fuels, and other hazardous fluids as they are consumed. Accordingly, technologies need to be developed to store, pump, and transfer these fluids, both at the SBSP and at the satellite. This problem is especially complicated for cryogens where the zero-gravity environment precludes a liquid/vapor phase separation which would otherwise facilitate fluid transfer. Additionally, cryogens present a significant boiloff problem which must be overcome to enable long-term storage in space. Other areas related to fluid storage and transfer which must be addressed are remote and autonomous operations, flow management, contamination control, and quantity measurement.

In addition, numerous other new technological areas will need to be applied to enable or enhance the SDI support concept. These include assembly of large structures in space, maintenance of electro-optical and reflective surfaces, artificial intelligence/expert systems, and computer-aided logistics. The development or application of these logistics-related technologies must receive equal priority with the technologies leading to the weapons and sensors that will be supported.

"NASA is aggressively pursuing the establishment of a capability to conduct on-orbit support operations."

A diverse and capable support architecture is an integral part of the SDS support concept of on-orbit maintenance and servicing. However, within the SDI research program, this area has not been developed to the same degree as have the technologies for the weapons and sensors. Fortunately, the on-orbit maintenance and servicing technology has blossomed outside the SDI in several areas having direct application to this SDS concept. NASA is aggressively pursuing the establishment of a capability to conduct on-orbit support operations. Several programs have been initiated that will produce hardware and technology to perform a variety of on-orbit maintenance and servicing activities. Furthest along is the OMV. NASA has awarded a design and production contract for one vehicle (with an option for second) to TRW, with the initial unit due to fly in 1993. This versatile vehicle can be equipped with an array of front ends to enable it to perform a variety of missions. A study is currently underway to examine potential DOD applications, including maintenance and servicing for SDI assets.[14]

NASA is also in the advanced concept development phase for a monopropellant tanker. Called the orbital spacecraft consumable resupply system (OSCRS), this vehicle is designed to transport several thousand pounds of either hydrazine or water, as well as gaseous helium or nitrogen. OSCRS will be carried aboard the Space Shuttle, controlled from the aft flight deck, and used to refuel satellites or supply fluids to the Space Station. Umbilical mating and demating will be performed by EVA using a coupler which has already been designed and built. The development of requirements for an automated coupler is now underway.

A production contract for OSCRS should be awarded in the late 1980s or early 1990s, leading to a flight-ready vehicle by the mid-1990s. Interestingly, a key technology for this vehicle (the ability to transfer hydrazine in a zero-gravity environment) was successfully demonstrated by the orbital resupply system (ORS) experiment on Space Shuttle flight 41G in 1984.[15]

NASA has also been active in the area of cryogen storage and transfer. In August 1987, NASA awarded three contracts for the competitive preliminary concept development work for a superfluid helium tanker. This work will lead to a production contract to deliver a flight-ready vehicle in 1996. This vehicle, the cryogen refueling tanker (CRTR), will be used to resupply cryogens to the next generation of NASA observatories, the Advanced X-Ray Astronomics Facility (AXAF), and the Super Infrared Telescopic Facility (SIRTF). These observatories have highly specialized sensors which must be cooled by volatile superfluid helium, requiring periodic replenishment to enable the sensors to observe the farthest reaches of the universe.

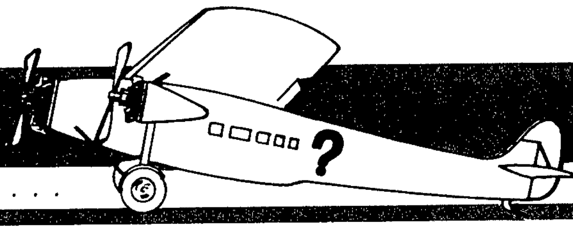
To further the cryogen storage and transfer technology, NASA is developing an experiment called superfluid helium on-orbit transfer (SHOOT). The SHOOT experiment is scheduled to fly in 1991 and will be the cryogen equivalent of the ORS. SHOOT will be used to demonstrate flow measurement techniques, mass gauging, and liquid helium containment techniques. This technology will then be transferred to the CRTR program.[16]

Finally, in the areas of robotics, NASA has extensive activities underway at the Goddard and Marshall Space Flight Centers and the Jet Propulsion Laboratory (JPL). A simple robotic ORU exchanger has been developed by Marshall and has successfully demonstrated the ability to remove and replace ORUs in a ground laboratory environment. A joint Goddard-JPL activity has just begun development of the flight telerobotic servicer (FTS). The FTS will be used around the Space Station to reduce the amount of EVA required of the astronauts to maintain the station. A preliminary version of the FTS should be available by late 1993. Preliminary specifications call for the FTS to have a modular hardware and software design, to be capable of being maintained on orbit, and to have the capacity for P^{3}I. NASA is also beginning to study the requirement for an autonomous robotic system to be used in conjunction with the OMV. This effort will lead to the identification of a complete robotic architecture needed to conduct servicing operations, including sensors, task planning, end effectors, and operator interfaces.[17]

Skeptics of on-orbit maintenance and servicing argue that it is too technologically complex to be feasible. Contrary to that opinion, this technology has actually made enormous strides in recent years and, in many instances, is more mature than the technologies needed to develop and deploy the weapons and sensors for the SDS. Others will say that NASA's hardware programs will not meet the specific requirements for maintaining SDS assets on orbit. True, the exact OMV, FTS, or OSCRS *may* not meet SDS needs; but these programs are developing technologies that can be *leveraged* or *tailored* to an

To page 41 ▶

Enquiring Loggies Want to Know . . .



Q. If only one area could be selected, what would be your top priority for improving our logistics "go-to-war" capability?

Respondent: Mr Lloyd Mosemann II, Deputy Assistant Secretary of the Air Force (Logistics), HQ United States Air Force, Washington, DC.

A. The obvious near-term answer is full funding of spares. However, a more fundamental answer would be reliability. We need to modify our existing aircraft and design new aircraft and other weapon systems, so they don't break. Then, when we go to war, all we'll need are the weapons themselves without the weight, cost, airlift, and training associated with also moving maintenance capability.

Respondent: General Duane H. Cassidy, Commander, Military Airlift Command, Scott AFB, Illinois.

A. I am convinced the C-17 offers the best solution for meeting our national policy goal of a minimum airlift capability of 66 million ton miles per day to support theater commanders who must actually go to war. We don't have that capability yet—the C-17 will help put us there.

But, that's not the whole story; you can't improve today's go-to-war logistics capability without also addressing the spare parts problem. We must increase the availability of spares for our fielded weapon systems. We can do this by shortening the turn-around time for pipeline spares, as well as purchasing new spares that improve the reliability and maintainability (R&M) of existing systems. Improving R&M would, in turn, mean fewer spares in the pipeline and a shorter turn-around time. Finally, adequate funding for the preferred spares program, with a goal of doubling reliability and cutting maintainability in half, will go a long way toward improving spare parts availability.

Respondent: General Alfred G. Hansen, Commander, Air Force Logistics Command, Wright-Patterson AFB, Ohio.

A. In AFLC, we are in the business of supplying combat capability to the using command. The primary reason we exist is to ensure Air Force weapon systems have the logistics support required to do the job. Only in that way will the war-fighting commands have the mission capability they need to protect this nation and its vital interests. Since customer support is really what we are all about, we must be "pro-user" all the way. That means closely identifying with the combat role which we are so much a part of. No matter how difficult a user's request may be, our response should always be positive—we should find a way to make it happen. Our mission is to equip and sustain the forces' war-fighting capability. To do this requires planning for many different war scenarios. We recognize the war we fight seldom matches the scenario for which we plan, so predicting what is required to sustain the force is difficult at best. To meet the changing demands dictated by battlefield conditions, the Air Force needs a logistics command and control system that is responsive to dynamic combat priorities and survivable in a hostile, heavy-traffic environment. This, coupled with improved logistics management systems and weapon system master plans, will allow AFLC to provide more responsive logistics support to the combat commands and significantly enhance our go-to-war capability.

Respondent: Major General H. N. Campbell, DCS/Logistics, HQ USAFE, Ramstein AB, Germany.

A. In short, we can improve our logistics go-to-war capability best by realistically exercising the present system. Let me expand on this thesis just a bit. My contention is that in every exercise, even ones like Wintex-Cimex which are supposed to test the logistics base, we only allow exercise play to go as far as the loss of the first real operational sortie. We then holler "kings - x" and either halt or modify the play. I've observed this during Salty Demo, during Wintex, and during several other exercises which purported to test the logistics capability of USAFE. We in USAFE have also sent folks to look at the Navy exercise base at Newport and to the Army's school at Fort Lee. Both have single service logistics exercises, but there is little global perspective in any of them, especially as that global perspective applies to inter-service cooperation.

The hardest part to a realistic exercise of any kind is accurate and timely exercise inputs on the part of the DISTAFF. It would appear to me that these kinds of realistic inputs are sadly lacking . . . in other words, we haven't thought through what is likely to happen in war, and so we haven't practiced.

Respondent: Major General Henry Viccellio, Jr., DCS/Logistics, HQ Tactical Air Command, Langley AFB, Virginia.

A. Enhance the survivability of our personnel and equipment in the combat environment. Given that we've got the airlift to get to our deployment location and the assets to sustain operations once we get there, we must ensure the survivability of our assets. Sufficient numbers of hardened shelters must be available to protect our aircraft, support equipment, jet engine intermediate maintenance (JEIM), avionics intermediate shop, petroleum, oil and lubricants, munitions, WRSK/BLSS, and personnel. Failure to protect these assets will surely preclude sustainability—the result, reduced or nonexistent combat capability. This answer may be a bit simplistic; however, if we cannot protect the assets we have, there is little sense asking for more.

Respondent: Brigadier General Joseph K. Spiers, DCS/Logistics, HQ Pacific Air Forces, Hickam AFB, Hawaii.

A. My top priority for improving our logistics warfighting capability is the development of an assured logistics command, control, and communications (Logistics C^3) system. The uncertainties of a wartime scenario, particularly in the Pacific Theater, make such a system a necessity. PACAF's scenario presents some different problems to solve, among them a relatively small force to cover a large area, vast distances between bases making the logistics chain more difficult to support, and scarcity of available airlift assets to move needed supplies around the theater.

Although not PACAF unique, there are many factors that occur during war which an assured Logistics C^3 system could help overcome. Here in PACAF these factors, when coupled with the distances, forces, and airlift available, make a viable Logistics C^3 system a necessity. For example:

a. Uncertainties in conflict: Our Logistics C^3 system must be responsive enough to react to changing conditions and operational priorities, unpredicted levels of asset consumption, loss or damage to logistics resources, and demand for assets not used in peacetime.

b. Malpositioned resources: Limited storage and maintenance facilities, political sensitivities of host countries, and scarcity of materiel result in our key resources not always being stored optimally at the location of use. Our Logistics C^3 system must be able to respond and "deliver the goods."

c. Transportation's responsiveness: Limited inter- and intra-theater airlift availability, coupled with PACAF's great distances, makes it imperative that our Logistics C^3 system respond in a manner that makes optimum use of our assets and lateral support. Even though we are trying to make our bases as self-sufficient as possible, higher than expected demand and attribution may limit the base logistics support capability.

d. Inability to guarantee base survivability: This problem, when considered with those already mentioned, leads to a situation where our limited airlift and long distances make it difficult to relocate our main bases rapidly. However, relocation will likely be a fact of life and we would encounter a situation of a scarcity of resources where they are operationally needed most. We need to work this contingency smartly and Logistics C^3 allows us to do just that.

Since there will never be enough support to meet all exigencies, we must be able to make best use of available logistics resources by reflecting operational priorities through a flexible and responsive system that can tell commanders at all levels what is available, where it is located, when they can get it, and how it will get to them. An assured Logistics C^3 system will provide the critical real-time information we need at all levels in a conflict.

Respondent: Brigadier General Charles J. Searock, Jr., DCS/Logistics, HQ Strategic Air Command, Offutt AFB, Nebraska.

A. The short answer is "Requirements Determination." Valid resource requirements must come from a common, well-defined base. Governing planning documents must focus on that common starting point and force the various requirements determination processes to flow smoothly and effectively from there to completion; for example, to "rubber on the ramp." First and foremost, planning scenarios used in the Defense Guidance, Joint Strategic Capabilities Plan, theater CINC operations plans, and service documents such as the Air Force War and Mobilization Plan must all be consistent in concept. Otherwise, inconsistencies and confusion in subsequent determination of requirements are sure to result. As a final hedge against Murphy's Law, the processes used to generate dollar-spending authorization documents (WCDO, WPARR, NCAA) must be flexible enough to compensate for any unanticipated demands or changes in requirements.

Respondent: Colonel Charles E. Roberson, DCS/Logistics, HQ Air Force Systems Command, Andrews AFB, Maryland.

A. To continue to push for repairable aircraft and systems—repairable in the combat environment. Today's weapon systems are much easier to maintain and certainly more reliable than their predecessors. We have proven we can sustain peacetime surges. The question is, "Can we do it in combat?" Are we building aircraft so intricate that we can't fix them in the field without elaborate support systems? Look at the size of the F-15 and F-16 Avionics Test Stations (AIS). Where would a unit be if their supporting AIS went down? Do we have enough spares in the system to satisfy our needs while we wait for the depot to repair the item? Probably not!

Another problem—aircraft wiring. We are going to fiber optics and fly by wire. How do we repair these kinds of things in a chemical war environment? Imagine working on paper-thin wire bundles with a chemical warfare suit on. How about battle damage? It's not a simple matter of remove and replace when the aircraft has taken a shell and has a hole in it the size of a watermelon. How do we repair that? Can we repair it? What if the shell hit some composite material? Can we "scab" patch it as we have in the past, or do we need something exotic to put the aircraft back in flying shape?

Finally, we seem to be relying more and more on the aircraft to tell us what is wrong with it. A great idea! But what if that system becomes unreliable? Will we have the time to run down false alarms? What if it fails completely? Can we work without it? Will the maintainers be able to troubleshoot and repair without the help of the on-board diagnostics?

As a maintainer, I think the efforts toward reliability and maintainability are super and necessary. But the bottom line for me is, "Can I repair the machine in a war environment like SE Asia, the Persian Gulf, or the Arctic, when the aircraft returns to a base with holes in it?" Can I turn it quickly and make it safe to fly, to do its job, or will it just sit there?

To improve our "Go To War Capability" we need to ensure repairability of the system in a wartime environment. We must not allow ourselves to become complacent with peacetime accomplishments, letting them convince us we can produce sorties from battle-damaged birds in hostile environments.

Respondent: Colonel Thomas Domingues, Jr., Chief, Air Logistics Division, National Guard Bureau, Washington, DC.

A. Improved reliability of weapon systems that would dramatically reduce our reliance on the large quantities of logistical support—people, spares, and support equipment—that must be deployed.

Defense Acquisition in 20 Years—A Prescriptive History

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Introduction

In the past, the Department of Defense (DOD) has been plagued by chronic problems in the way it acquires weapon systems. These problems fall into three categories: the high cost of modern weapon systems, the performance and complexity of those weapon systems, and the lengthy acquisition cycle necessary to bring them into DOD inventory.[1] In attempting to deal with these problems, Congress and DOD initiated numerous studies[2] which have resulted in a plethora of actions intended to improve DOD's weapon systems acquisition process; however, the chronic problems have not been solved. In this article, the authors examine these continuing acquisition problems and discuss some adverse trends that occurred over the past 20 years. They then suggest some solutions that could reverse the adverse trends over the next 20 years.

To do this, the authors employ a useful long-term planning approach advocated by the late Herman Kahn[3]—they write a prescriptive history of the weapon systems acquisition process for the next 20 years, from the vantage point of the year 2008. Twenty years was selected because it is sufficiently long-term for considerable innovative change to take place, yet not so distant as to suggest that "proposals" be regarded as mere intellectual fantasy.

Chronic Problems and Trends in Defense Systems Acquisition (1967-1987)

Declining Military Readiness[4]

In his book *Defense Facts of Life: The Plans/Reality Mismatch,* Franklin C. Spinney concludes:

> From the perspective of what has happened in the past, there exists a chronic mismatch between short-term decisions (or desires) and long-term behavior (reality). In the short term, attempts have been made to hold down operating budgets (personnel, operations and maintenance, and readiness-related procurement) while increasing budget growth in procurement budgets to modernize U.S. military forces.[5]

According to Spinney, in the long run, the only way operating budgets could be maintained was by shrinking the size of the forces, thereby resulting in decreased readiness. As a result, DOD has been forced to acquire fewer and fewer weapons due to their ever-increasing costs. DOD has maintained, however, that US weapons are technologically superior to those of the Soviets and this technology advantage acts as a "force multiplier" to offset the US quantitative disadvantage. Of course, it is not DOD policy to shrink US forces, reduce readiness, or slow modernization. Stated policy and plans have indicated exactly opposite goals for the past 20 years; however, actual patterns and trends are contrary to these stated goals. There has been a bias toward underestimating future operating costs of a new weapon system. This occurs because program advocates must show their weapon system to be affordable before Congress will appropriate funds, and there is a natural tendency to be overly optimistic about unit production costs and future operating costs. The resulting "unexpected" cost growth is financed by simply procuring fewer and fewer systems.

Although cost overruns in DOD programs have attracted public criticism, cost overruns have not been a chronic problem in the acquisition of weapon systems. In a 1986 research report published by The Rand Corporation, the authors concluded that "cost growth in defense programs is now no greater than in civil programs of similar character and complexity and is probably a good deal less."[6] (Figure 1)[7] The real "cost" issue in DOD weapon systems acquisition is striking the proper balance between the complexity of a weapon system and the quantity of the system that can be purchased for a given budget.

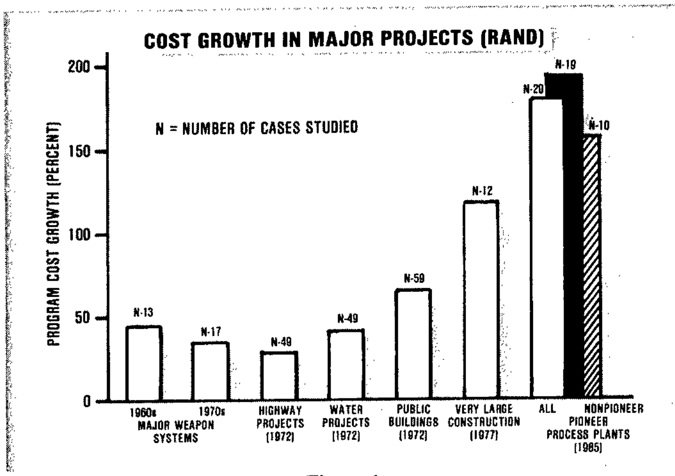

Figure 1.

Generally, as weapons have become more complex, their operating costs have increased significantly. This can be readily seen from the examples of tactical aircraft statistics over the past several years (Figure 2).[8] The complexity of these tactical aircraft can be measured through Materiel Readiness Indicators used in their daily maintenance. Table 1 reflects that the more complex the system is the more time that system is not mission capable (NMC); the fewer mean flying hours between failures (MFHBF); and the more maintenance man-hours per sortie (MMH/S). Simply stated, complex aircraft are more expensive to operate and maintain.

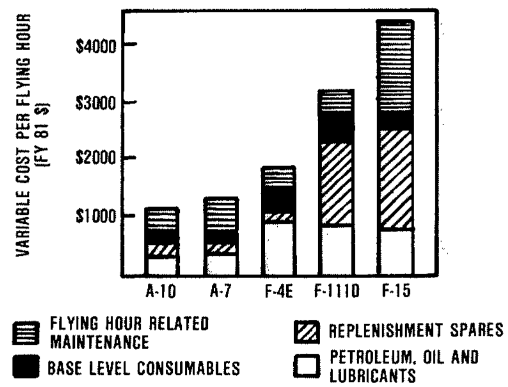

Figure 2.

These data reflect that increased complexity generates increased operating and maintenance costs.[10] Because of this unprogrammed expense, the Air Force was constrained to buy fewer tactical aircraft than planned, which has reduced overall combat readiness. It is clear from Figure 3 that during the past 35 years, the Air Force's active aircraft inventory has decreased significantly.[11]

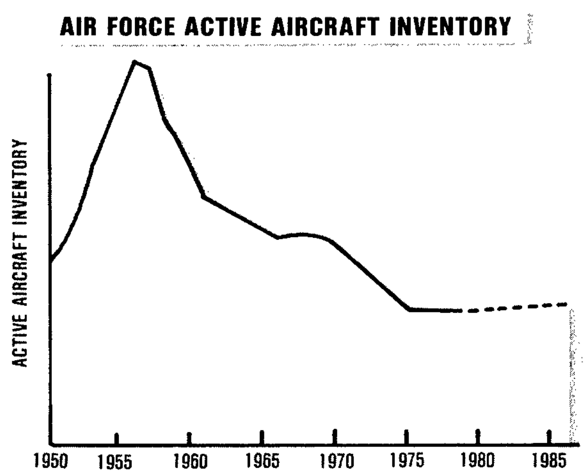

Figure 3.

In addition, the high cost of spare parts has mandated that the Air Force buy fewer war reserve spare parts kits. For example, according to Spinney, as originally planned, the F-15 was to have a 30-day peacetime stockpile of spare parts; however, due to the high cost of these spare parts, this was decreased to a five-day supply. This means that each F-15 squadron can operate in combat for only five days before it becomes dependent on shop repairs as opposed to the simple removal and replacement of "black boxes" (line replaceable units). The low MMH/S for the F-15 reflected in Table 1 are attributable to counting only the time required to remove and replace a black box, not the time required to repair it. Spinney estimates that by implementing the five-day plan each F-15 squadron saved $97 million.[12]

A less obvious (but no less critical) factor that has contributed to decreasing US military readiness is a shift of the defense industry to non-military products. Congressionally mandated changes in annual procurement rates and cancellations or delays of programs have forced companies to

TACTICAL AVIATION MATERIEL READINESS INDICATORS (FY 1979)[9]

Aircraft	Complexity	MFHBF	MMH/S	NMC
A-10	Medium	1.2	18.4	32.6
A-7D	Medium	0.9	23.8	38.6
A-4E	Medium	0.4	38.0	34.1
F-15	High	0.5	33.6	44.3
F-111F	High	0.3	74.7	36.9
F-111D	High	0.2	98.4	65.6

Key: MFHBF—mean flying hours between failures
MMH/S—maintenance man-hours per sortie
NMC—not mission capable

Table 1.

diversify for self-protection, and some companies have even left the defense business altogether.

Lengthening the Acquisition Cycle

Another adverse trend that occurred during 1967 to 1987 was lengthening the acquisition cycle—the interval between the conception of a new weapon system and its operational deployment.[14] The reason for this can be traced to several factors.

A major factor has been DOD's attempt to "push" the state of the art and develop weapon systems from unproven technologies. In a world of dynamic technological growth, DOD program managers have tried to incorporate promising new technologies into programs already in development. In addition to lengthening the development time, this has often resulted in cost growth, increased operational complexity, and increased maintenance requirements without meaningfully enhancing the military utility of the system.

A 1986 Rand research report, *Improving the Military Acquisition Process,* claimed the production phase of the acquisition process was being stretched out, "primarily for budgetary reasons." It concluded the stretchout "contributes to the aging of the weapons inventory" and "to cost growth, especially when (as is typical) stretchout leads to repeated disruptions in production rate."[15]

Other factors that have contributed to a lengthy production phase are: failure of defense industry to modernize production facilities (defense items are manufactured in some of the oldest plants in the United States, and investment in new capital equipment has been low)[16] and the need for long lead-time components, such as forgings and castings. Production capacity has simply not been adequate to fill the demand for these items in a timely manner. As a result, backlogs developed and lead times increased dramatically for aerospace castings; for example, lead times of 10-20 weeks in 1972 increased to 50-80 weeks in 1982.[17] The capacity of energy intensive industries, such as refineries and mills, which convert raw materials into processed materials, was also adversely affected by three energy crises during the 1970s (1973, 1976, and 1979).[18] High interest rates in the 1970s combined with small tax incentives also discouraged firms from investing in new capital equipment. All these factors

have contributed to declining defense industrial productivity which, in turn, has increased production lead times for manufactured products.

The chronic problems and adverse trends examined, as well as some widely publicized "horror stories" about overpriced spare parts, prompted individuals in both the public and private sectors to criticize the DOD acquisition process. In 1985 President Reagan responded to the criticism and the diminishing public confidence in the defense acquisition system by establishing the Packard Commission, which was chartered "to evaluate the defense acquisition system, to determine how it might be improved, and to recommend changes that can lead to the acquisition of military equipment with equal or greater performance but at lower cost and with less delay."[19] The Packard Commission Report, published in June 1986, advocated a series of major reforms to make the defense acquisition system more efficient. Similarly, Congress also responded to the need for acquisition reform by enacting the Goldwater-Nichols Department of Defense Reorganization Act of 1986 and the Defense Acquisition Improvement Act of 1986. These executive and legislative reforms are being implemented; however, their effect is yet to be determined. With this as a foundation, we will postulate the future of the DOD acquisition system over the next two decades based upon current reform directives and our own suggested formulae for improvement.

A Prescriptive History of the Weapon Systems Acquisition System (1988-2008)

The Joint Weapons Acquisition Agency (JWAA)

In response to an emphasis on joint military operations beginning in the late 1980s and the concomitant pressures to streamline the DOD acquisition process, the Secretary of Defense directed that a single agency be created to develop, test, and procure all DOD weapon systems. In 1990, the Joint Weapons Acquisition Agency (JWAA) was formed with military and civilian personnel from the three Services' acquisition commands, which have remained virtually intact; however, these commands now report to JWAA rather than their Service headquarters. Today, the JWAA is comprised of almost 100,000 Acquisition Corps personnel, 75% of whom are civilians. These military and civilian personnel are carefully trained and managed to ensure career progression through general/flag officer rank (or civilian equivalent), with career broadening assignments in operational commands, principally the unified and specified commands.

Since its founding, the JWAA has espoused a management philosophy of "centralize—only when necessary." JWAA recognized that a strong, central and coordinated focus was needed to exploit and integrate the unique capabilities of each Service, eliminate wasteful and undesirable duplication, and assure a common analytic approach in dealing with a multi-faceted national threat. Hence, JWAA centralized monitoring of joint research programs; concept development; cost analysis; allocation of funds to each program; contract administration; and DOD data acquisition. All other functions have been decentralized to the individual Services where they are more effectively performed.

The past 20 years have also been characterized by a significant reduction in Service parochialism. Prior to formation of the JWAA, the Services competed with one another for portions of the DOD budget. The JWAA forced cooperation among the Services by providing an atmosphere which both encouraged and demanded joint participation. Funds which were formerly provided to the individual Services for research, development, and acquisition are now provided to the JWAA for allocation to program managers. This joint focus has resulted in acquiring numerous systems with common logistics support, which has significantly reduced operational and maintenance costs. The JWAA made some hard decisions such as canceling major programs which failed to achieve their specified baseline performance and canceling some planned new starts in order to preserve stable funding of ongoing programs. The JWAA has produced many significant results through its management of the DOD acquisition process:

(1) Reestablishment of public confidence in government procurement by eliminating Service parochialism in weapon systems acquisition, streamlining the DOD acquisition system, and centralizing control of DOD acquisition funds.

(2) Acquisition of weapons designed for specific joint military operations by a joint organization.

(3) Significant savings in the aggregate cost of DOD weapon systems attributable to the acquisition of multi-mission weapons, versus Service-unique weapons, and to greater commonality between the Services' equipment.

(4) Additional savings to DOD by participating in the acquisition of multi-role systems that are owned and operated by non-DOD agencies during peacetime, yet dedicated to specific military missions during war. (Examples of the peacetime roles of these systems are drug interdiction, coastal defense, border patrol, and medical evacuation.)

(5) Cost savings through greater use of off-the-shelf and commercial products and previously developed military components.

(6) Acquisition of a greater quantity of less sophisticated weapons in response to a change in military strategy based upon the increased threat of low-intensity conflict in Central and South America.

(7) Reduced technological risk in acquisition programs resulting from technology baselining (or freezing) during the concept formulation phase.

(8) Increased combat readiness through reduced dependency on depot maintenance and more reliance on field maintenance.

(9) Development and retention of Defense Acquisition Corps professionals through carefully structured personnel policies.

(10) Increased use of multi-year contracting as a result of increased program stability.

(11) Extensive use of mission-oriented performance specifications versus overly restrictive design specifications.

(12) Improved cost estimating resulting in reduction of cost overruns to less than 10% on virtually all programs.

The JWAA has not been the only factor in improving the DOD weapon systems acquisition process. Congress also contributed to reversing the adverse trends that prevailed during the 1967-1987 period.

The Congressional Office for Oversight of DOD Acquisition

In response to the public clamor for acquisition reform, the 103rd Congress instituted a major innovative change. It

created the Congressional Office for Oversight of DOD Acquisition (COODA), responsible for oversight of all DOD weapon systems acquisition. This organization freed congressional staffs from the burdensome technical analysis and micromanagement of DOD acquisition programs and placed a dedicated, highly skilled staff of acquisition professionals at the fingertips of all members of Congress. In concept, the COODA is similar to the General Accounting Office—a non-partisan "watchdog" of Congress.

The COODA staff developed open lines of communication with key DOD acquisition professionals (Defense Acquisition Executives, Service Acquisition Executives, Program Executive Officers, and Program Managers). In the same cooperative spirit, the JWAA's management established an "open program" policy and encouraged staff members of COODA to become involved in all JWAA programs at the beginning. COODA staff members attend formal program reviews at which they obtain complete program and technical data Congress considers essential. They also ensure congressional concerns are surfaced for consideration by the JWAA.

The benefits of the COODA to the DOD acquisition process have been enormous:

(1) Information flow and mutual understanding and cooperation between DOD and Congress were greatly improved.

(2) Congressional requirement for DOD to submit detailed, time-consuming reports was drastically diminished since the COODA provides a continuous flow of timely information to Congress.

(3) Large volume of congressional hearings requiring DOD input was significantly reduced.

(4) Better cost estimates have facilitated accurate, long-term budgeting which has resulted in more program stability (stable production rates).

(5) Stability of DOD programs has, in turn, induced more industrial participation in DOD contracts, thereby revitalizing the defense industrial base.

(6) Unexpected cost growth was ameliorated through COODA's independent cost estimates of new weapon systems.

(7) Congress has not, since 1995, needed to enact a Continuing Resolution for DOD appropriations at the beginning of each fiscal year.

(8) Because of COODA's direct involvement in the acquisition process, Congress has helped restore public confidence in the DOD acquisition system.

Changes in the Weapon Systems Acquisition Process

For the past 40 years, a continuous debate has been waged concerning the quality versus the quantity of new weapon systems acquired. The central issue in this debate is whether a smaller force of sophisticated weapons employing high technology (quality) can defeat a larger force of rugged, relatively non-sophisticated weapons (quantity). The "quality" advocates maintain that during the development of new weapons, we should attempt to incorporate all the latest technologies, including those that push the limits of the state of the art. In the past, this has resulted in much higher program risk, higher cost, and a lengthier development cycle. In the late-1980s, DOD attitudes toward high technology weapons started to shift. DOD officials began to heed the lessons of history. High technology was not the decisive factor in World War II, nor did it produce a decisive victory for us in Korea, for the French in Indochina, or for the US in Vietnam.[20] In 1986, the Packard Commission concluded: "At some point, more weapons of lower performance can overcome fewer weapons of higher performance."[21]

DOD attitudes concerning "quality" were dramatically influenced by the espionage cases of the Walkers and Whitworth, who were convicted in 1986 of selling highly classified defense information to the Soviets. This "technology leak" continued during the 1990s with the free flow of information from West to East in open literature; the irresponsible release of classified information by government officials; US sales of high-technology equipment in foreign markets, where problems were encountered even with countries believed to be friendly to us; and both military and industrial espionage. A rude awakening came in the mid-1990s when DOD realized the Soviets were no longer simply copying our technology, but had become a designer-producer of high-tech military products. The US lead in weapons technology almost disappeared in the late 1990s. At that point, DOD recognized that reliance upon superior technology as a "force multiplier" was ill-founded, and DOD began to subscribe to the philosophy that "quantity has a quality all its own."[22]

Requirements Determination—A Joint Focus. The DOD acquisition process now begins with a clear definition of operational requirements. The Goldwater-Nichols Department of Defense Reorganization Act of 1986 changed the manner in which weapon systems requirements are determined. Congress elevated the requirements process to the highest level possible, to the Chairman of the Joint Chiefs of Staff (JCS). The Chairman, by law, now serves as the spokesman for the commanders of combatant commands, especially on the operational requirements of their command. However, not until the argument over whether the cruise missile should be added to our strategic Triad did the unified and specified commanders assume their preeminent position in establishing operational requirements for new or modified systems. Statements of need (SONs) are now developed or sponsored by a commander of a specified or unified command. They are then sent to all other unified and specified commands for review and comment prior to being submitted to the JCS for validation. If one of the Services develops a SON, it must be sponsored by a combatant commander in order to be forwarded to the JCS for validation. After the validation phase, the concept development/cost analysis phase begins at the Joint Weapons Acquisition Agency. It is through this organization that all the Services participate in developing alternatives to satisfy the stated requirement. There are no cost constraints during this phase; however, costs associated with each alternative concept are eventually weighed in the final decision of which weapon system to pursue. One great benefit to the concept development/cost analysis phase is that it has been shortened.

Research and Development. Despite DOD emphasis on fielding greater quantities of less complex weaponry, a vigorous research and development (R&D) program has been pursued, fueled by the realization that such a program is essential to avert another Sputnik/ICBM technological surprise. Congressional fear that the Soviets might gain first access to some "ultimate weapon," as we did with the atomic bomb, stimulated the funding of a more extensive R&D program within DOD. In this regard, Strategic Defense Initiative R&D continued at a rapid pace, and the Strategic

Space Defense System reached initial operational capability in 2001.

A large R&D effort was directed at technologies to improve our capability for conducting low-intensity conflict. One of the most significant results of that effort was the creation of an air-to-air rearming capability for fighter aircraft. It provided benefits equivalent to those provided by air-to-air refueling. Another benefit of the expanded R&D program was the development of unmanned, remotely piloted aircraft for use in intelligence, communications, and weapon delivery.

The Packard Commission recommendation to build prototypes as a matter of course for all major weapon systems was fully implemented in 1989. This prototyping facilitated an early assessment of the benefit of new technologies in improving military capabilities, and it established a basis for more realistic cost estimates. Also, as recommended by the Packard Commission, operational testing is now routinely begun early in advanced development, using prototype hardware, and the prototyping cycle has been shortened to two years for most systems.

In 1990, the chief DOD scientist was assigned to JWAA and given the responsibility of overseeing and coordinating all research activities sponsored by DOD. Oversight responsibilities extend to research conducted by the Services in their numerous laboratories and to research accomplished pursuant to government contracts with universities, corporations, and federal contract research centers.

An important R&D initiative was adopted by the Secretary of Defense in the early 1990s. Upon recognizing that Congress was not going to fund DOD's R&D adequately to explore all the Project Forecast II concepts,[25] the Secretary sought industrial participation to "supplement" the DOD budget. He had his staff identify those Project Forecast II concepts that had great potential for commercial application. He then shared DOD's basic research with various defense contractors and persuaded them to conduct R&D concept studies at corporate expense. This partnership between DOD and industry yielded many advanced technologies that DOD alone could not have afforded. An example is the development of a new non-nuclear explosive that filled the enormous gap between the yield per pound of conventional ordnance (TNT) and that of nuclear weapons. This breakthrough in explosives technology was developed by an oil exploration company, revolutionizing that industry. It facilitated the extraction of unprecedented amounts of oil from deep shale deposits. Additionally, this extremely high-powered, low-weight explosive greatly increased the lethality of DOD's conventional weapons.

Full Scale Development. Two significant changes were made to the full scale development (FSD) phase of the DOD weapon systems acquisition process: the requirement for performance and technology baselines (PTBs), and the practice of direct congressional oversight (by the COODA) during FSD.

One of the important concepts that was implemented in the 1980s was weapon system baselining. In essence, this concept called for a contract between the program manager and top DOD management concerning a weapon's performance, cost, and schedule goals—essentially, management by objective during FSD. In the late 1990s, DOD required that an additional factor be baselined—technologies. This was the result of problems which occurred during the 1960s-80s: lengthened FSD phases and increased costs due to high risk technologies that simply did not pan out. Now technologies must be demonstrated during an advanced development period (basic and applied research) at military or civilian laboratories before they are incorporated into FSD programs.

Production. During the late 1980s and the 1990s, revitalizing the military-industrial base became a high DOD and congressional priority because of its vital importance to military readiness. Great success was achieved in this area as a result of the efforts by DOD and Congress to stabilize weapon systems acquisition programs.

Multi-year procurement has been a great testimonial to the success achieved by Congress and DOD working together to improve the acquisition process. By planning for and executing production runs on selected weapon systems for three years of DOD requirements, industry has been able to achieve economies and efficiencies in the production process. Industry's tremendous cost savings were shared with its customer, DOD.

JWAA recognized that, after a company was awarded a three-year production contract, that company became insulated from further competition for the duration of the contract, thereby eliminating its incentive to become increasingly more efficient. Therefore, to overcome this, JWAA employed the selective practice of "dual sourcing" production of weapon systems. Such dual sourcing ("split buys") created head-to-head competition which resulted in great savings to DOD, not only in subsequent buys but particularly in the acquisition of replenishment spare parts.

Another successful cost-reduction program was Value Engineering,[24] which received renewed emphasis from DOD. Government contractors rose to the challenge of innovation in design and production processes in order to increase shareholder profits. Savings to DOD were "plowed back" into the product to achieve even greater quality, for when a Value Engineering Change Proposal was approved, the contract was also modified to include a specification for minimum mean time between failure of the affected system. This, in turn, resulted in lower life cycle cost.

Finally, DOD achieved success in reducing the length of the acquisition cycle by making an important "make or buy" decision of its own concerning critical long-lead items. Because of the excessive time required by industry to produce forgings and castings, in 1992 the Secretary of Defense decided to develop an organic DOD capability to produce those critical components. This government-operated manufacturing facility supplemented the existing DOD remanufacturing operations at the air logistics centers and naval shipyards. This program was a resounding success, for DOD was able to produce quality components in less time than they could be acquired from the civil sector. DOD manufactured forgings and castings were then provided to the production contractor as government furnished property.

The progressive production changes occurring over the past two decades have greatly enhanced industrial preparedness; DOD's purchasing power; and, most importantly, military readiness.

Net Result

Using a prescriptive history approach, the authors have suggested numerous changes to improve the DOD weapon systems acquisition system from 1988 to 2008. They postulated an acquisition process that is more responsive to meeting the changing military threat, that produces more cost-effective weapon systems, and that delivers new weapon

To page 35.

Evolution of Cost Accounting Systems: What the Project Manager Needs to Know

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Introduction

One of the unique features about military contracting is market prices do not exist for most strategic items. In addition, many follow-on contracts are given to the same firms. In these circumstances, prices often must be negotiated based on the costs of products. The Air Force, for example, normally allows 11% to 15% profit on weapon systems manufacture.[1] Hence, understanding how military contractors handle costs is important to the project manager. Brig Gen John Slinkard, Director of Contracting and Manufacturing Policy(SAF/AQC), emphasizes that "we are engaged not only in a negotiation process but, to a great degree, in a cost justification process."[2]

Frequently, it is reported that many defense contracts include inflated costs. For example, General Electric pleaded guilty to making false claims and statements in connection with Air Force contracts to update reentry vehicles on the Minuteman Missile[3] and a contract for 50 C-5B airplanes awarded to Lockheed was overpriced by as much as a billion dollars.[4] Consequently, the Department of Defense (DOD) is increasing the scrutiny of contract costs.[5] Congress, skeptical whether the Pentagon has cracked down hard enough on defense contract cost control, is stepping up investigation of contractor fraud.[6]

Purchasing military supplies at fair prices is important for several reasons. First, the amount of military purchases is enormous and, therefore, even a small percentage overcharge involves a large dollar amount. Second, the overcharge must eventually be paid by federal taxes; therefore, this issue affects the political and social environments of the country.

Confronted with challenges from overseas competition, many US manufacturing firms have experienced major changes in their production processes and in their accounting information systems during the past few years. The purpose of this paper is to introduce the basic concepts of the new manufacturing system, Just in Time (JIT), and to discuss the resulting current developments in cost accounting. Some desirable changes that might occur in the near future under the new environment are also discussed. In the determination of fair prices, it will be vital for military contract officers and project officers to understand the new cost accounting system.

JIT System

It has been widely reported that many US firms have lost their competitive edge to foreign counterparts. Japanese firms in particular have increased their market share to a remarkable extent in various industries. Many factors can be attributed to the success of the Japanese manufacturing companies in the international market. While some authors mention Japanese culture and Japan's unique business environment, many have concluded that the unique manufacturing system, JIT, has played a key role, helping to produce high-quality products at low cost.

Following Japan's lead, many US companies have recently adopted JIT manufacturing. Some of these firms successfully improved product quality and at the same time reduced manufacturing costs.[7] Due to the initial successes of the JIT system in many manufacturing firms, it is expected that more firms in the US will adapt their manufacturing process into a JIT system in the future.

The JIT concept, originally developed by Toyota to control inventory, is explained in a nutshell by Richard Schonberger:

> Produce and deliver finished goods just in time to be sold, subassemblies just in time to be assembled into finished goods, fabricated parts just in time to go into subassemblies, and purchased materials just in time to be transformed into fabricated parts.[8]

This JIT operating cycle is depicted in Figure 1 as a demand-pull system.[9] As shown, the JIT idea permeates all the major functions of a manufacturing firm. The sales department estimates demand in the immediate future for products. It then places a JIT order for finished goods with the manufacturing department, triggering a production schedule. Raw materials are purchased and delivered on a JIT basis to meet the production schedule. In the manufacturing department, one work center makes only the parts required in the next center. Finished goods are ready for delivery at the appointed time.

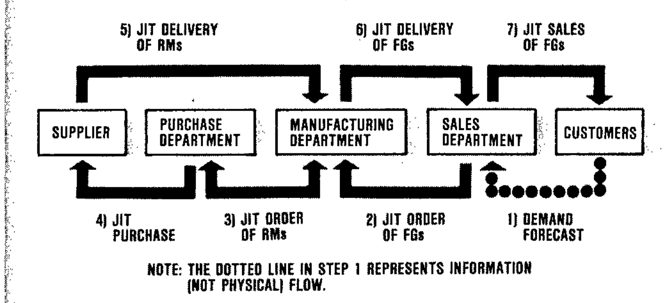


Figure 1: JIT Operating Cycle.

While this system is a large departure from traditional contracting and manufacturing processes, it should not be difficult to adjust to, except for learning new terminology and scorekeeping methods. It is similar to the activities a tactical fighter unit goes through in order to deliver specific munitions on a particular target at a given time. Aircraft mechanics, supply personnel, petroleum, oil and lubricants (POL) delivery personnel, munitions handlers, and loaders—every ground person—and the aircrew must do their job right, in turn, within a time frame that allows the finished job to be completed at a precise moment.

The JIT system requires several major changes in the traditional operating process:

JIT Purchase and Delivery

JIT purchasing is a basic requirement for successful JIT production. Quick delivery of high-quality parts from suppliers is crucial because only materials needed immediately are purchased. Hence, reliable suppliers with total quality control commitment should be selected for longer periods. Frequent deliveries of small orders also assure defects are discovered early and corrective actions, if needed, can be taken immediately. It would be beneficial to both a manufacturing firm and its suppliers to be located close together. When suppliers' plants are geographically near the buyer, there are shipping cost advantages as well as numerous coordination benefits.

Total Quality Control

Quality of work in process is checked while the work is being done. The goal of this quality control process is perfection—zero defects in the finished goods. Also, every item, not just a random sample, is inspected to achieve that goal. Early warning and continuous monitoring systems are employed. A worker can stop the production line when a defect is found and work flow remains stopped until the problem is corrected. (Think what happens when a safety violation is found on the flight line.) A side benefit of the heavy reliance on workers' self-inspection is a reduction in the number of industrial quality control inspectors at the end of the production line.

Flexible Work Force

Workers are trained to operate work centers rather than one machine. They may be rotated through every processing job in a factory for a period of time. Labor flexibility enables the firm to reassign employees as necessary to produce the products and models demanded. When a worker is having problems and experiencing delays, other workers can be assigned immediately to solve the problems by concentration of force. Regular workers also perform other tasks, such as data collection and analysis, quality control, machine maintenance, and minor repairs. Multi-skills provide employees with some protection against layoffs, and workers find their jobs less boring.

Total Preventive Maintenance

To prevent equipment failures that have the potential to shut down a production line, workers who use the machines must perform daily checkups, repair, and maintenance. Maintenance is performed during downtime. Zero defects in the equipment help produce zero defects in finished goods. In addition, workers have a feeling of ownership of the equipment they handle every day, promoting care in its use and lengthened service life.

Short Setup and Lead Times

To respond to the changes in orders by the sales department, short setup time is essential. Commercial machines and tools may be altered for quick setup and the company's own engineers and workers can build their own machines. Short lead time is also important in the manufacturing department because finished goods are ordered on a short-term basis in JIT firms. Short setup and lead times make it possible to reduce inventories of finished goods and of work in process to a minimum level.

Changes in Cost Accounting

Cost accounting in a manufacturing firm measures and reports information about costs during the production process. Therefore, any changes in the manufacturing process will result in corresponding changes in the cost accounting system of the firm. The changing production methods in manufacturing industries have made traditional cost accounting concepts and models obsolete in some cases, and more changes are yet to come. Hewlett-Packard first introduced JIT at a new printed circuit fabrication facility in 1983. The company is now well known for its success in implementing JIT. Several model cases of changes have been experienced by divisions of Hewlett-Packard.

Insignificant Direct Labor Costs

To achieve the goal of zero inventories and zero defects, automation of production systems is required. Computer integrated manufacturing (CIM), especially, links all functions of a firm so it can respond to changes in customer demands on short notice. The result of automation is to make labor costs insignificant, relative to total production costs. At Hewlett-Packard, after adopting JIT, direct labor costs comprise only 3% to 5% of product costs and only 1% of inventory costs.[10] Consequently, many Hewlett-Packard divisions treat direct labor costs as indirect costs which were traditionally handled by expensing them when incurred. Since direct labor costs are eliminated from product cost categories, they are no longer directly traced to each job, which saves a lot of transactions and journal entries. It is questionable whether the traditional approach adds anything to accuracy, but it clearly is more expensive and less efficient.

JIT Product Costing System

In conventional cost accounting, direct materials, direct labor, and manufacturing overhead initially flow into work in process. Total costs are then transferred to finished goods when products are completed and to cost of goods sold when they are sold. However, as noted, at Hewlett-Packard direct labor costs are directly charged to cost of goods sold, and they also charge overhead as an expense to cost of goods sold as incurred. They found that tracking overhead through work in process and finished goods provided no useful information due to reduced lead time and low inventory levels in their JIT system. Moreover, they found that this simplified costing method, presented in Figure 2, eliminated about 100,000 journal entries per month.[11]

In an ideal JIT environment where lead time is shorter than an accounting period, the product costing system can be further simplified. All manufacturing costs including direct materials can be charged directly to cost of goods sold when they are incurred, and at the end of each period an adjusting entry is made to finished goods from cost of goods sold to record ending inventory. Since the ending inventory is low

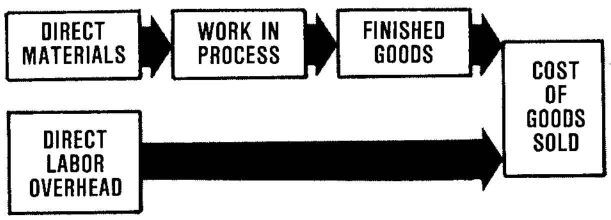


Figure 2: Hewlett-Packard Costing System.

under JIT, counting the unsold units should be an easy task (Figure 3).[12]

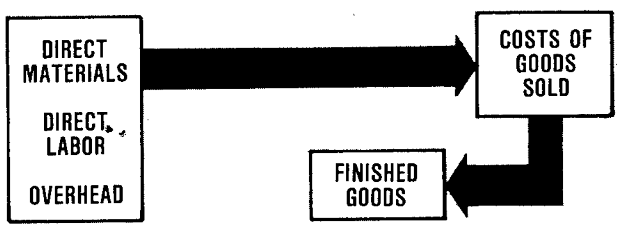


Figure 3: JIT Costing System.

But many JIT firms do not work in an ideal environment. Hence, they must design their own product costing system so accounting is simplified and at the same time product costs more accurately estimated. Blind adherence to traditional cost systems (job order costing and process costing) will result in expensive inefficiency and inaccuracy in estimating product costs. W. Holbrook argued that present cost accounting systems are too restrictive and complex to be of any value to JIT implementation.[13] The accounting systems need to be modified to be more flexible and simple.

Inventory Valuation and Recording

Low-inventory levels simplify inventory valuation to a great extent. The difference between last-in/first-out (LIFO) and first-in/first-out (FIFO) would be meaningless for firms implementing JIT. A disadvantage of this consequence is those firms cannot defer tax payments by using LIFO. However, there will be less room for these firms to manipulate costs by changing inventory levels, which will result in more accurate cost figures and, thereby, in more realistic net income and inventory values.

For JIT firms, the periodic inventory method would not be useful because of the need for tight inventory control and quick inventory turnover. Inventories should be checked daily and updated in order to help monitor purchasing and manufacturing schedules. This JIT inventory recording method is more accurate than the perpetual inventory method because the physical counts are taken daily rather than once at the end of each period. In the perpetual inventory method, every inventory transaction is recorded but is verified by counting only periodically.

Overhead Allocation

For JIT firms, overhead allocation becomes more important due to a significant increase in overhead.[14] Traditionally, direct labor hours have been widely used in allocating overhead. This method is based on the assumption that manufacturing overhead is directly related to direct labor hours. This assumption would be valid in traditional labor-intensive industries. In an environment in which direct labor costs are relatively trivial and do not reflect labor efficiency, direct labor hours are no longer appropriate as an allocation base. Hewlett-Packard, after adopting JIT, found the production cycle time required to process one unit of finished goods was a better predictor of overhead costs.[15]

Schonberger also supports the use of production lead time as a base of overhead allocation. He argued the method is fair because most of the overhead charges are for time spent dealing with delays and problems that add to lead time, and the method is clever because it induces the supervisor to cut lead time which is essential to successful implementation of JIT.[16]

John Lee suggests the use of multiple allocation bases using a microcomputer:

> . . . it may be possible to find a set of cost pools for which there is only one cost driver; i.e., the factor that explains why that level of costs has been incurred. There may be dozens of cost pool sets. When the goal of finding homogeneous drivers is achieved, then perform calculations on personal computers using spreadsheet software. For even dozens of those drivers, calculations would not be a problem thanks to the availability of PCs and software.[17]

Reduced Rework and Material Waste

A major benefit of the total quality control associated with JIT is less rework and less material waste. Schonberger observes that when JIT leads to reduced scrap and more good parts, the time and money spent on rework drops and so does the cost of wasted materials.[18] The result is a more simplified accounting system with less transactions. Hewlett-Packard, after implementing JIT, found the amount of scrap and rework dropped and therefore proportionately less effort was required to collect the costs of scrap and rework.[19]

Easy Cost Data Collection

Cost collection is easier in a JIT environment because cost flows are simple and straightforward and the cost system may be automated. Automation of cost collection by personal computer reduces the cost of the accounting system substantially and adds to the ease of analyses and monitoring of manufacturing costs.

Under the JIT environment, these six areas of cost accounting will affect the military purchaser's estimations of product costs because cost plus pricing, popular in military contracts, allows the contractor reimbursement on the basis of final cost of products plus a specific percentage of cost. Therefore, the negotiated price of the product can be significantly affected.

Conclusion

The United States must continue to make strides in production processes and accounting information systems to keep this country competitive. Program managers may have already signed contracts with companies implementing JIT or will have opportunities to deal with such firms in the future as the number of organizations adopting JIT increases. Project

To page 4 ▶

Civilian Career Management

The AFCPMC Management Information System

The Management Information System (MIS) is now available to all Civilian Career Programs assigned to the Career Management Division, Air Force Civilian Personnel Management Center (AFCPMC/DPCM), Randolph AFB, Texas, after an intensive three-year development effort sponsored jointly by AF/DPC/LEY. This capability provides an interactive data retrieval and management information system for the career programs managed by the Career Management Division. Thirteen career programs are using MIS with additional career programs scheduled soon for on-line access.

In 1983, an independent analysis of the Logistics Civilian Career Enhancement Program (LCCEP) identified the need for additional support to eliminate extensive manual processes in the program. In February 1985, the LCCEP Policy Council approved the modular concept to develop automation enhancements with current resources and put them in use as each module was completed.

Since completion of Phase I on 30 November 1987, the MIS has alleviated much of the manual processing at AFCPMC and met the information needs of management in career programs by bringing an automated capability to the Center. Longer-range, Phase II will continue development of the MIS effort in its present configuration.

The backbone of MIS is data extracted from the Personnel Data System - Civilian (PDS-C) "CAE" file located in the Air Force Military Personnel Center's (MPC) Honeywell Computer. These data extracts, generated on an end-of-month (EOM) basis, are loaded to a VAX 11/780 computer and used to update six different databases for each career program to review and manage data in separate functional areas.

MIS provides a set of menus that allows access to each of the databases. Data structures and procedures are also provided to allow direct use of the databases through DATATRIEVE, the VAX data retrieval/reporting software package.

A brief description of the databases provided to each career program and some of the MIS features are:

(1) The REGISTRANT database contains two types of data:

a. PDS-C data consisting of personal identification, appraisal ratings, current position, duty location, job address, and career registration data.

b. Additional data input manually and separately maintained by each career program. Some data is standard (phone numbers and penalties), but generally it varies in purpose for each career program. Manual data is unaffected by EOM updates.

The menu allows the user to view current end-of-month displays of changes in the database. Other displays present distributions of the registrants by grade with regard to command, duty location, or occupational series. Other menu options include access to appraisal ratings, education, promotion, or penalty data for an individual.

(2) The GEOGRAPHICAL AVAILABILITY database provides data showing a program registrant's geographical availability as entered on AF Form 2675. Up to 160 geographical availability locations are stored on the database, along with the grade level desired and supervisory or nonsupervisory preference.

The menu can display geographic availability for all individuals by grade for locations specified in the database. The same report can be generated for a specific occupational series.

(3) The POSITION CONTROL database provides data for all positions managed by the career program. The user can view any one of 57 displays for current end-of-month data. The displays provide information on centrally managed, career essential, career broadening, and intern positions.

(4) The CAREER DEVELOPMENT database contains employees who are defined as Career Broadeners, PALACE ACQUIRE INTERNS, Presidential Management Interns (PMIs), or COPPER CAPS (exclusive to the Acquisition Career Program). The user can review current end-of-month displays of current Career Broadeners by grade, location, and command.

(5) The TRAINING database consists of personal data and required, requested, and scheduled training along with training history. The menu can also generate a listing of potential students who have indicated a preference for specific courses. This multi-optioned program allows the career programs to select those who have expressed an interest in a course, using AF Form 1556, or those who have not requested the course but are eligible to attend.

(6) The PEP MANAGEMENT module uses manually entered data on the POSITION CONTROL database. This menu permits review of statistics on the number of positions identified with PEPs for a given occupational series. Also, the user can list all positions of a certain occupational series sorted by either Civilian Personnel Control Number (CPCN) or PEP number.

The capabilities afforded by the implementation of MIS greatly enhance management's ability to review the voluminous data available from PDS-C. It has already proven itself many times by providing data on numerous special projects for functional logisticians to better manage their work force.

(Source: Ron Wong, AFCPMC/DPCMLD, AUTOVON 487-5631)

Logistics Professional Development

Logistics Plans Officers: The Key to Logistics Success

Logistics plans officers contribute significantly to the success of every logistics command, wing, headquarters, and staff agency in the Air Force. Because of their widespread impact, many young officers often ask the Logistics Officers Assignments people at HQ AFMPC about the requirements to enter this interesting field. AFR 36-1, *Officer Classification,* provides a summary of the duties and responsibilities of the logistics plans officer and lists the qualifications for entering the logistics plans career field. Since logistics plans encompasses all facets of the logistics business, officers are drawn from supply, maintenance, transportation, and contracting. Aircraft, missile, and communications-electronics maintenance officers are included in the maintenance area.

Before discussing the logistics plans field, we need to view the total logistics officer force. Figure 1 shows a breakout by AFSC of functional areas comprising the logistics officer force, with 16% of the people in logistics plans. Figure 2 shows the core areas making up the present logistics plans field. Many of the officers now in logistics plans have previously served in other areas and have had their primary AFSC changed to logistics plans (AFSC 66XX); hence, ratios are different from Figure 1. In most cases, those people from other logistics areas will return to their primary AFSC after tours in logistics plans.

Authorizations by command are shown in Figure 3. Air Force Logistics Command has a significant demand for logistics plans officers, primarily in acquisition logistics and life cycle support. Tactical Air Forces also have a great demand for logistics plans officers—with greater emphasis in mobility planning and execution at base level.

Figure 4 depicts the breakout of authorization distribution and levels of assignment throughout the Air Force. Figure 5 shows the total authorizations by grade for the logistics plans career field. There are many opportunities for major and major selectees. Figure 6 depicts manning trends for the field with the projected manning levels for FY88.

Logistics plans is a diverse, challenging career field. With many opportunities to plan for combat support and integrate logistics career fields, there is a good opportunity to be a direct contributor in improving combat readiness. With USAF's greater reliance on well-developed war plans, and life cycle cost analyses for acquisition management, logistics plans offers a real challenge. If you are interested in entering the logistics plans field, fill out a Form 90 and let AFMPC know of your interests.

(Lt Colonel Roomsburg, PALACE LOG, AUTOVON 487-5788)

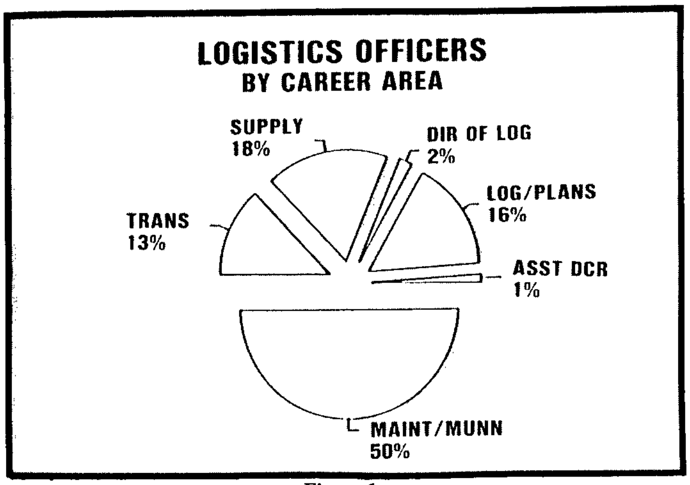
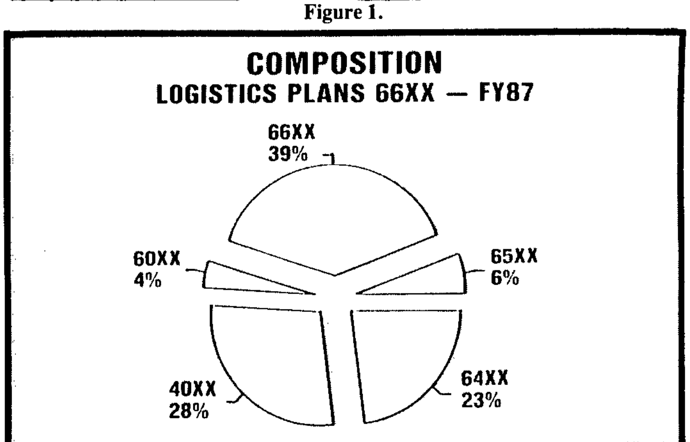


Figure 1.



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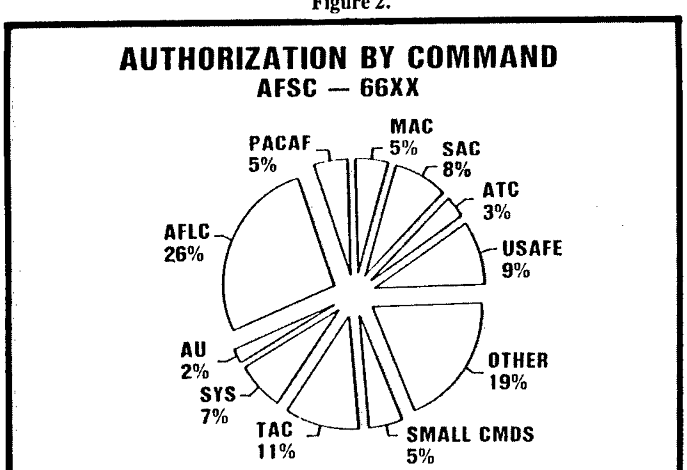

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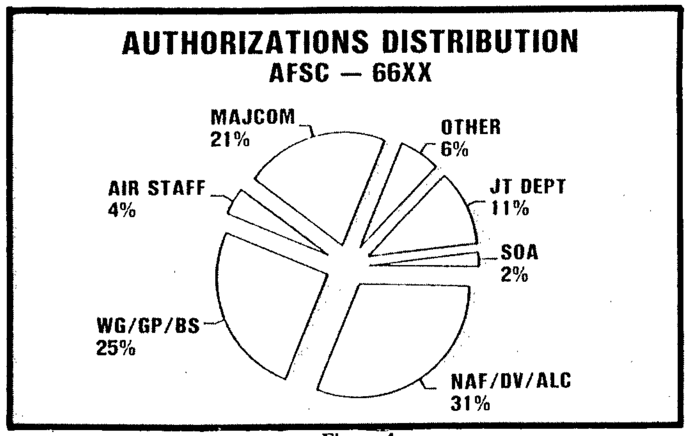
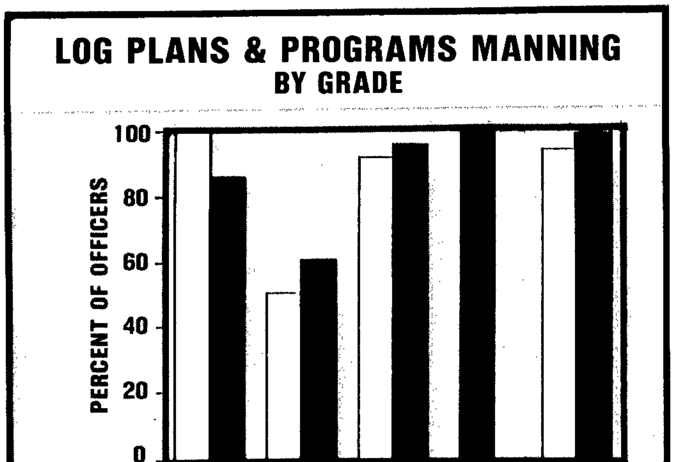
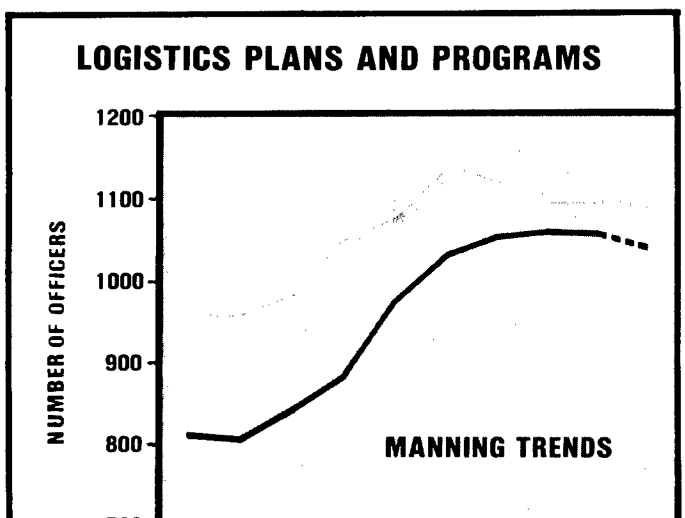


Figure 4.



	LT COL	MAJ	CAPT	LTS	TOTAL
66XX	103	51	92	0	94
LOG AVG	86	61	96	298	99
# AUTH	168	453	485	0	1106
# ASGN	173	229	448	195	1045

Figure 5.



	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	*FY88
PERCENT	84	83	85	83	90	90	94	96	96	95
AUTHORIZED	972	970	994	1062	1087	1148	1126	1108	1107	1099
— ASSIGNED	815	809	845	885	977	1034	1056	1062	1059	1042

Figure 6.

Improved WRM Policy

During the 1987 War Reserve Materiel (WRM) Conference at Wright-Patterson AFB, 27-29 October 1987, a primary issue was the need to improve WRM policy guidance. The general consensus was that a significant rewrite of AFR 400-24, *War Reserve Materiel Policy,* was required to improve, clarify, or expand standardized policy guidance. We want to ensure that all functional areas and WRM commodities are adequately covered in the new AFR 400-24. In view of the substantive policy changes anticipated, a working group will be convened at the Pentagon, 25 January-February 1988, to accomplish the rewrite. AF/LEXX will chair the working group which will consist of representatives from Air Staff functional areas and a small group of WRM experts selected for their background and understanding of WRM at various levels in different MAJCOMs. The product of the working group will be a revised AFR 400-24, which will then be formally coordinated with the MAJCOMs. (Lt Col Robert Tiggemann, AF/LEXX, AUTOVON 225-2175)

AFR 28-31

AFR 28-31, *Base Support Planning,* is scheduled for publication by March 1988. The regulation will require a base support plan to be published by every installation with a wartime mission. Base support planning has four basic objectives: continuing mission support to identify those functions and activities necessary to support the installation mission for the duration of the conflict; deployment support to identify those activities, resources, and procedures to receive, bed-down, and outload transiting or deploying forces; integration of in-place and incoming units to assure effective command and control as well as allocation of resources; and documentation of limiting factors, shortfalls, and overages. Regardless of which office is designated as OPR for the base support plan, logistics activities will have a major role in developing the plan. (Lt Col Jim Folz, AF/LEXX, AUTOVON 225-2175)

AFR 28-4

Change 1 to AFR 28-4, *USAF Mobility Planning,* is currently in coordination, with publication anticipated in early 1988. Primary reason for the change is to formalize numerous waivers granted under the Model Installation and Logistics Excellence Programs. The thrust of these changes is to simplify the base-level mobility process by allowing units to tailor requirements to fit their needs. For example, the personnel and functions of the traditional mobility organization can be modified as desired as long as basic requirements are met. A major objective of the January 1988 USAF mobility conference is a complete rewrite of AFR 28-4 to streamline the mobility process further by eliminating unnecessary requirements and identifying peacetime only requirements. Mobility is a unit responsibility with four basic objectives: the right people and equipment must be deployed, they must be deployed on time, they must be deployed safely to assure arrival, and they must use minimum transportation.

Tool Tiger Team

The Air Force established a Tool Tiger Team (T^3) to address common hand tool proliferation and enhance on- and off-equipment flight line maintenance. The T^3 has developed two lists which define those common hand tools desired for future flight line maintenance. The Standard Tools for Aeronautical Repair (STAR) list contains only 329 items; however, it represents all the common hand tools desired for future on- and off-equipment aircraft and related support equipment maintenance. The Standard Tools for Aeronautical Removal and Replacement ($STAR^2$) list contains only 47 items and defines those common hand tools desired for all on-equipment maintenance; this list capitalizes on the modular design of new components and systems. The $STAR^2$ list will be included in the acquisition process for use by the designers of future weapon systems in the development of maintenance concepts. When fully implemented, the STAR lists will make many current tools obsolete and eventually reduce the number of tools needed in an average composite tool kit to less than a dozen. (CMSgt Jim Chambers, AF/LEYY, AUTOVON 227-9179)

Weapon System Warranty Policy

The Air Force has long recognized the importance of ensuring product quality in fielded weapon systems and equipment through the use of warranties, guarantees, and various performance incentive arrangements (product performance agreements). The Defense Procurement Reform Act of 1985 (Title 10, United States Code, Section 2403) reemphasized the importance of warranties by enacting permanent statutory requirements for warranting weapon systems entering mature full-scale production. A new Air Force regulation is in work to fully implement the new warranty requirements. AFR 800-47, *Weapon System Warranties,* will provide policy and procedures, and assign responsibilities for acquiring, administering, and reporting on the effectiveness of weapon system warranties. The draft AFR 800-47 establishes planning requirements and mandates close cooperation in the development of warranty provisions and required administrative system between the using and supporting commands. The final draft AFR 800-47 has been sent to all major command and Air Staff agencies for review and is scheduled for publication in early 1988. (Lt Col Bill Foster, AF/LEYM, AUTOVON 227-1493)

Logistics 2010

Dr. Robert Costello, Assistant Secretary of Defense, initiated the Logistics 2010 project to develop comprehensive

DOD-wide strategies to guide the Department into the twenty-first century. Logistics 2010 is designed to integrate strategies among the logistics functions across military services, Defense Logistics Agency (DLA), and the unified and specified commands. A major emphasis is incorporating new technologies into DOD strategic long-range planning. While long-range planning projects have been tried in the past by DOD, Logistics 2010 aims to be different by tying directly into the budget process to ensure we will be ready to support the weapon systems of the next century. Logistics 2010 will use existing planning processes within the participating agencies as a baseline for study. Within the USAF, the strategic planning process is managed under the Director of Logistics Plans and Programs (HQ USAF/LEX). AFR 400-13, *Long Range Planning,* provides basic guidance for strategic planning and specifies forums such as the annual "Future Look" Conference to review directions for the future. (Lt Col Jon Zall, HQ USAF/LEXY, AUTOVON 225-1015)

Logistics Command and Control (LOG C²)

There is no documented Air Force-wide LOG C² Concept of Operations which provides guidance for the full spectrum of operations from peace to war nor which describes the decision-making information flow from the lowest echelon to the National Command Authority. Future Look 87 established a tiger team chartered by HQ USAF/LE, XO, and SC to document the USAF wartime organization and identify decision-makers; determine the essential logistics information they need; develop a broad LOG C² concept of operations; and develop an action plan for the near, mid, and long term. Since the tiger team ends in June 1988, the effort was scaled down to include only the USAF in wartime, recognizing and documenting the interfaces with other services, nations, etc., focusing on supply (to include munitions and fuel), maintenance, and transportation. (Lt Col Cannava, AF/LEXY, AUTOVON 225-6785)

Expense Investment Criteria

The long-awaited congressional decision on the new threshold limit for Expense Investment Criteria (which includes Base Procured Investment Equipment) is nearing a final resolution. The DOD proposal to increase the unit cost threshold from $5,000 to $25,000 met with disparate views in the Authorization Committees; the House Armed Services Committee (HASC) disapproved this proposed increase and the Senate Armed Services Committee (SASC) approved it. Moreover, the final Authorization Conference position revises the threshold to $15,000 for FY88 and 89 and restores it to $5,000 in 1990. In order to assist Congress in establishing future unit cost dollar limits for such items, the conferees will direct the GAO to conduct a study in 1988 (to be completed by 1 January 1989) on procurement expense for equipment. On the Appropriations side of the House, the House Appropriations Committee (HAC) approved a $25,000 threshold, while the Senate Appropriations Committee (SAC) has not yet made a determination. It appears the final outcome may be contingent upon how the SAC, which generally supports the SASC position, makes its mark. (Ms Ethel Jones, AF/LEXP, AUTOVON 225-7031)

▶ Continued from 28

systems in a shorter time. Ultimately, the acquisition process of the future, after two decades of reform, should restore public confidence in DOD's management of public funds and enhance military readiness.

Notes

[1] *A Quest for Excellence, Final Report to the President by the President's Blue Ribbon Commission on Defense Management,* David Packard, Chairman (Washington DC: US Government Printing Office, June 1986), p. XXII.

[2] Examples are: The Fitzhugh Report, 1980; The Commission on Government Procurement Report, 1972; The Acquisition Advisory Group Report, 1975; Report of the Acquisition Cycle Task Force, 1978; Defense Science Board 1980 Summer Study on Industrial Responsiveness, 1981; etc.

[3] Smith, Major General Perry M. "Creating a Strategic Vision: The Value of Long-Range Planning," *Air University Review* (September-October 1986), p. 17.

[4] The phrase "military readiness" refers to the capability of a unit, a weapon system, and related support equipment to respond promptly and perform the mission or function for which it is organized or designed. Military readiness also includes force structure (number, size, and composition of forces) and sustainability (staying power of endurance).

[5] Spinney, Franklin C. *Defense Facts of Life: The Plans/Reality Mismatch* (Westview Press, Boulder, Colorado, 1985), p. 116.

[6] Rich, Michael and Dews, Edmund. *Improving the Military Acquisition Process* (Santa Monica, California: The Rand Corporation, 1986), p. vii.

[7] Ibid., p. 11.

[8] Spinney, p. 53.

[9] Ibid., p. 52.

[10] *Defense Facts of Life: The Plans/Reality Mismatch* contains numerous other examples of Army, Navy, and Air Force systems that have consistently shown increasing costs and complexity, decreasing quantity, and decreasing military readiness.

[11] Spinney, p. 23.

[12] Ibid., p. 35.

[13] *Study of Increasing Lead Times in Major Weapon Systems Acquisition,* Doty Associates, Inc. (Rockville, Maryland, 1981) p. 3-26.

[14] Rich and Dews, pp. vii and 13-17.

[15] Ibid., p. vii.

[16] Ibid., p. 45.

[17] *Study of Increasing Lead Times in Major Weapon Systems Acquisition,* p. 3-3.

[18] Ibid., p. 3-2.

[19] *A Formula for Action, A Report to the President on Defense Acquisition by the President's Blue Ribbon Commission of Defense Management,* April 1986, p. 1.

[20] Tilford, Major Earl H. Jr. "The Real Stuff," *Air University Review* (September-October 1986), pp. 14-15.

[21] *A Formula for Action,* p. 15.

[22] This comment is attributed to V. I. Lenin, one of the founders of the Soviet Union.

[23] Project Forecast II was a 1986 Air Force Systems Command (AFSC) initiative to identify promising technologies and systems concept that have the potential of improving tomorrow's Air Force by a revolutionary leap forward. A committee of 175 military and civilian personnel from AFSC, the Air Staff, and the operational commands sifted through some 200 ideas generated by Air Force laboratories, industry, academia, and the participants themselves. The committee identified more than 70 high technologies and concepts ripe for exploration and exploitation over the next 20 years.

[24] The Federal Acquisition Regulation explains the concept of Value Engineering in section 48.1: "Value engineering is the formal technique by which contractors may (1) voluntarily suggest methods resulting in savings or (2) be required to establish a program to identify and submit to the government methods for performing more economically. Value engineering attempts to eliminate, without impairing essential functions or characteristics, anything that increases acquisition, operation, or support cost."

USTRANSCOM Established

The United States Transportation Command (USTRANSCOM) was formally activated with ceremonies at Scott AFB, Illinois, in October. General Duane H. Cassidy, Commander in Chief, Military Airlift Command, is the first CINC of the USTRANSCOM.

USTRANSCOM will be responsible for strategic mobility planning, automated data processing (ADP) integration, and support for the other unified and specified commanders in chief during strategic mobility execution.

Measuring, Evaluating, and Controlling Production and Inventory Systems of Government Contractors

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PART I: Introduction and Literature Survey

This two-part article (second part to be published in Spring issue) addresses production and inventory control (PIC) systems, specifically those used by contractors working on government contracts.

Production and inventory control (PIC) systems are extremely important to the manufacturer and have been described as the nervous system through which the manager controls production operations. Whether the manufacturer is building for the public or serving as a government contractor, profitability (and thus capability to stay in business) often is determined by the effectiveness of control over production and inventory systems.

Manufacturing organizations use PIC systems to determine the amount of materials and components needed to support the manufacturing rate and to determine manufacturing lot quantities. The central function of an effective control system is to maintain minimum investment in materials consistent with operational requirements. The goal is to ensure an adequate stock of all items needed to maintain operations and to keep investment in materials and work in progress (WIP) at optimum levels.

A problem exists in poorly designed PIC systems that leads to increased manufacturing costs and decreased productivity. It is the use of "workarounds" caused by premature material acquisition/production. These holding costs include the cost to maintain inventory levels, rework or scrap costs caused by obsolescence, material losses, and the cost of capital associated with WIP and stockroom inventory. This article is concerned with PIC systems, specifically those used by contractors working on government contracts.

Production/Inventory Control Systems

The target population of top defense contractors typically dedicates a portion of its resources (e.g., division) to government contracts. Government contract work generally accounts for 90% or more of that division's total output. These contractors use various combinations of fabrication and assembly operations for production, and production to government contracts may involve quantities of one unit or several hundreds of thousands. As a result, production may be scheduled in small batches as in a job shop, or the volume may justify establishing continuous production facilities. In spite of the variability among contractors' production operations, they have several things in common.

Figure 1 depicts the common management process of planning, scheduling, and control. Production planning is part of contract negotiation and uses the signed contract to set subordinate activities in motion. The contract contains specific statements regarding technical performance (quality), scheduled delivery dates, and costs. Master production scheduling (MPS) uses these requirements to incorporate a contract's production into existing schedules. The MPS may deal with the final production to be delivered by a specified date or may go to a more detailed component level. At this point, production and material planners determine the detailed material requirements and estimate the firm's capability to satisfy these requirements internally. Material destined for internal production becomes part of the detail schedule to be implemented in the various work centers. Material which must be obtained from external sources is passed to purchasing for either vendor or subcontractor action. Shop floor control ensures production occurs as scheduled or takes preventive or corrective measures to resolve problems.

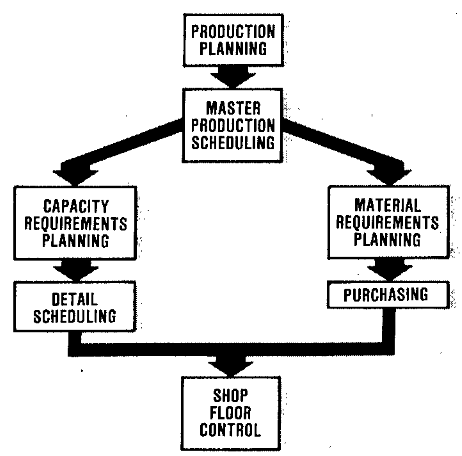

Figure 1: Manufacturing Planning, Scheduling, and Control Systems.

Production and inventory control actions are implicit in the planning, scheduling, and control systems. The action of scheduling at any level implies a due date derived from the contractor's required delivery data. This is obviously true for internal production, but it is also true for material obtained from either vendors or subcontractors. Scheduling requires an estimate of the time to purchase or fabricate or assemble some components. This time estimate, or lead time, together with an estimate of lead time variability and due date for a particular item, yields a time for action: procurement, fabrication, or assembly.

If procurement, fabrication, or assembly is started too late, the contract's delivery schedule will probably not be met. Conversely, if any of these actions are started too early, material of WIP inventories may be higher than required, but a contractor's delivery schedule will probably be met. Any firm's efforts to control production of inventories must start with a program to obtain realistic estimates of lead times and their variability to identify start times. Purchasing and shop personnel must, in turn, adhere to these scheduled start times. Management information systems must identify how much time a job spends in work, in transit, and in queue. Queue time must be driven to a minimum, subject only to the amount necessary to deal with lead time variability and obtain a reasonable utilization of resources.

The federal government can borrow at a lower rate of interest than contractors; therefore, it routinely provides ". . . contract financing through progress payments." (FAR 32.500) "Since the Progress Payments clause gives the Government title to all the materials, work-in-progress, finished goods, and other items of property described . . ." in the clause, the government has a vested interest in reducing WIP inventories. (FAR 32.503-14)(27)

"Work in process inventory" is generally viewed as any material on which the purchasing company has spent company resources (labor, time, money) to turn it into a saleable product, but which is not yet viewed as a finished product ready for sale.

This broad definition includes material purchased against a contract but not yet involved in production, and subcontractor or vendor WIP which has been paid for through the contractor's use of progress payments to subcontractors or vendors. In summary, materials acquired specifically against a government contract are owned by the government.

The problem addressed in the two papers of this series is how to evaluate PIC systems with the specific focus of discovering a method for effectively measuring and controlling WIP inventory.

Literature Survey

Use of Progress Payments

Progress payments are payments which are made to contractors prior to the delivery of the completed product. Customary progress payment rates are currently 75%, 80% for small businesses, of the total cost of performing a contract. (FAR 32.501-1)(28) They are made so the contractor's financial position will not be unduly burdened during the course of a long, expensive contract. There is strong evidence the current procedures for making progress payments are very favorable to contractors, at the expense of the taxpayers. We reviewed several government reports which address these issues.

Kaitz (16) discusses in broad terms problems which he perceives in the current methods of pricing major weapon system contracts which currently operate much the same as public utilities. Basically, the public has no choice but to pay the price demanded by the contractor. The free market system alone is not working for major weapon systems and cannot work for a number of reasons. Therefore, some regulation of the process is essential. This regulation should be wholistic in nature, rather than the piecemeal fine tuning which has been attempted in the past.

Another problem addressed in Kaitz's report is that many factors make it unattractive for contractors to invest in productivity-enhancing measures. Among these factors are DOD policies and actions which artificially alter the industrial structure in which weapon systems are produced. Such actions make it extremely difficult for contractors to accept the risk of large capital investments, since they cannot be sure if, how, when, or for how long the investment may be used. Kaitz concludes that some amount of regulation of contractors is essential, but it is important that procedures are based as much as possible on "free market" concepts. Another important recommendation is that multi-year contracts should become more common, so contractors can reduce the unit costs of weapon systems over time and pass along these cost reductions to their customers.

Tucker (26) reports on findings obtained during an audit of DOD policies on the use of progress payments. The first major issue in this report was the appropriateness of current progress payment rates. The rates were raised during the economic downturn in 1981. Since 1984 progress payment rates have been reduced twice:

Apr 1985	Large business from 90% to 80% Small business from 100% to 90%
Fall 1985	Small business from 90% to 85%
Oct 1986	Large business from 80% to 75% Small business from 85% to 80%

The report concluded that then current rates were excessive given better economic conditions. Lowering rates to their pre-1981 levels would save the government an estimated $250 million per year in interest costs and would have reduced FY 1985 budgetary cash outlays by approximately $2.1 billion. It is strongly recommended in the report that a system be developed to monitor current economic conditions and progress payments rates, and to adjust the rates if warranted. Tucker also finds that some contractors have failed to review subcontractors' progress payment requests properly. As a result, some subcontractors received premature and excessive progress payments.

Meling (19) reports on an audit of seven selected Air Force Plant Representative Offices (AFPROs). The report concludes procedures were generally accurate but some administrative contracting officers were not fully complying with regulations in four areas. Contract officers often failed to ensure authorized alternative liquidation rates were properly supported by contractor cost data, or to certify their continued validity annually. These officials also failed to compare data on quarterly limitation on payment reports for price revision contracts to cost data on contractors' requests for progress payments. They also failed to compare the fair value of undelivered work to the amount of unliquidated progress payments. One contract officer did not require the contractor to identify separately the price and costs related to firm fixed-price items from the price and costs for fixed-price incentive items on the progress payment requests. Based on these findings, Meling (19) concludes the overall system of progress payments is adequate. The problems outlined, however, point out the need for greater care and more attention to detail on the part of some AFPROs regarding the regulation of progress payments.

The referenced reports can be summarized as follows. The manufacturers of major weapon systems operate in an environment much like that of public utilities; some regulation is necessary, but it should be based on "free market" concepts

whenever possible. Progress payments are necessary in order to maintain a sound financial position for weapon systems contracts. The current system of progress payments is generally adequate, with the following exceptions:

(1) A system should be developed to monitor current business conditions and adjust progress payment rates accordingly.

(2) More care should be taken by AFPROs and, presumably, their counterparts in the other services, in the actual administration of the progress payment system.

(3) More care should be taken by contractors in reviewing subcontractors' progress payment requests.

Measurement of Performance and Productivity

The measurement of performance and productivity is of concern to any organization. It is especially important in the case of firms engaged in work on government contracts. First of all, the government needs to know if contractors are maintaining an acceptable level of performance. Contractors also need to follow their own performance closely to ensure they are achieving desired levels of profit on their contracts and to aid them in gaining new contracts in competitive bidding situations. The article by Engwall (8) summarizes much of the work being done in the area of contractor productivity measurement.

The DOD has initiated several programs in an effort to motivate contractors to achieve higher levels of productivity. Sink, et. al. (23), under Air Force Contract, reported on such programs as Manufacturing Technology (MANTECH), Technology Modernization (TECHMOD), multi-year contracting, accelerated depreciation, cost-sharing for new equipment and processes, and other programs. In addition to productivity improvement programs, the government is increasingly interested in methods for measuring contractor productivity. The Sink report also outlined various productivity measurement theories and techniques.

The report stressed the need to distinguish between formal productivity measurement techniques and other, more traditional methods of measuring improvements in productivity. The distinction is important since formal productivity measurement techniques can be proactive by actually driving and facilitating productivity control and improvement.

The Sink study described in detail three generic productivity measurement techniques: (1) the Multi-Factor Productivity Measurement Model, (2) the Multi-Criteria Performance/Productivity Measurement Technique, and (3) the Normative Productivity Measurement Methodology. The third method is a structured participative approach to developing productivity and performance measurement, evaluation, control, and improvement systems. The study also identified a number of surrogate productivity measurement approaches that measure variables highly correlated to productivity, but not a direct ratio of output to input.

Norton and Zabel (20) produced a report for the Army as part of a study to develop and test measurement systems designed to complement the DOD Industrial Modernization Incentives Program (IMIP). The measurement systems were to provide a productivity measurement and tracking system, and also establish a base for contract incentives to motivate contractors to improve productivity. The report recommended the following three measurement techniques for testing in a contractor environment: (1) the Multi-Factor Productivity Measurement Model, (2) the Cost Benefit Analysis/Cost Benefit Tracking Methodology, and (c) shared saving techniques.

The literature on productivity measurement which has appeared in technical and trade publications is very general (9). These sources discuss such issues as the objectives of productivity measurement systems, system characteristics and requirements, and how productivity measurement information should and should not be used. For example, Stewart (24) presents a multiple-input productivity measurement model which utilizes data available within the manufacturing data base. The model was designed to meet the following detailed objectives for production organizations:

(1) Relate all significant inputs to the production of the organization's output.

(2) Include those controllable resources which are under the justification and management responsibility of the manufacturing manager.

(3) Remove the impact of inflation in both inputs and outputs.

(4) Account for product mix shifts.

(5) Do both absolute and trend analyses of individual inputs and the total system as an aggregation of those inputs.

Equations are presented which model system output, direct labor input, manufacturing support input, energy input, material input, inventory input, and production equipment. These measures can be examined individually or aggregated to measure total productivity. An overall ratio can be formed which relates the output as standard to the specific inputs at the actual levels of usage during the current review period.

A similar productivity measurement system was developed at the American Productivity Center (APC) in Houston and reported on by Hamlin (12) and APC (2). The APC system analyzes trends of multiple inputs as they relate to total output. The system includes all significant inputs and adjusts for inflation so the total impact of productivity and inflation on the firm's profitability is measured over time. A unique feature of this system is that it attempts to show a relationship between productivity measurement and financial accounting. Touche Ross & Company has created a system based on the APC results for identifying opportunities to increase productivity. (5) The Touche Ross model views profitability increases or decreases as resulting from either price recovery change, which is a change in the relationship between the unit selling price and the cost unit input, or productivity change, which is a change in the amount of input used to produce a unit of output. By tracking these two variables over time, a company can study the effects of changes and identify opportunities for productivity improvement.

Husain, et. al. (15), used an analysis based on queuing theory to develop relationships between the effectiveness of four areas of production control—purchasing, scheduling, loading, and sales—and total company performance as measured by the sales-to-stock ratio. They suggest the method can be used to indicate which of the four areas has the greatest impact on a firm's overall performance if control in that area is made more effective. The study also found that company performance can be markedly improved by reducing the production time per unit. Efforts to reduce setup times are particularly promising since they make smaller lot sizes economical.

A number of papers deal with productivity measurement in various specific situations or environments. Wilhelm (30) and Wilhelm and Doty (32) developed a capacity rating (CR)

index, which is the probability that workload (W) is less than or equal to the availability (A) of the work center. Relationships are developed for the single work center case to describe workload output and workload backlog in terms of CR, A, W, and their moments. An analysis for a flowshop environment was also presented, as well as an evaluation of the relationship between the static CR measure and dynamic shop operations as measured by mean lead time, lead time variance, and mean time in the shop. The CR methodology is proposed as an economical alternative to computer simulation for studying a particular facility.

Roll and Rosenblatt (21) describe a continuous production productivity measurement model for the single project management environment. An aggregate productivity index is formed by combining "duration productivity" with the productivities of other inputs. "Duration productivity" considers the time value of money over the duration of the project in computing the productivity of financial inputs. Productivity is then the ratio between standard and actual financial inputs.

Salas Fumas and Whinston (22) discuss a model based on geometric programming which incorporates price changes in a contract but still provides incentives for the producer to be efficient. The expected results are contracts which can differentiate between cost increases that result from ineffective management and increases that result from uncontrollable external factors, such as inflation. If price changes occur, and the producer can demonstrate that efficiency levels have been continuously met, this may convince the buyer to allow the price changes to be passed on. The authors give examples which illustrate the use of the model to provide both exact and approximate bidding formulas, as well as to monitor productivity over time.

Design and Control of Production/Inventory Systems

Anstead (1) lists common attributes of effective "closed-loop" manufacturing control systems: shared data requirement, real time access, data accuracy, and company-wide support and education. The term "closed-loop" implies the planning functions which feed the execution functions also receive feedback so replanning can occur.

Bell (3) examined two-stage production systems with intermediate storage. Limits were placed on the size of the buffer inventory, as well as the flow rates into and out of inventory. A comparison of results for cases with unconstrained lines, cases with flow constraints, and cases of unbalanced lines yielded the following significant points related to design issues: (1) the capacities of the transfer systems into and out of inventory should be about equal and (2) if storage is limited, an additional unit of storage capacity will yield greater production than an additional unit of transfer system capacity, but as storage capacity is increased, the situation is reversed.

Wilhelm and Sastri (33) also looked at two-stage flow lines, with emphasis on the start-up period. They found that learning, i.e., the increase of processing rates over time, tended to decrease the duration of the start-up period. They also found that buffer storage had less influence on the production rate than manufacturing progress.

Hillier and Boling (14) present results which indicate how the optimal allocation of work changes as the number of work stations increases, the amount of WIP storage space increases, and the variance of operation times decreases.

Sugimori, et. al. (25), compares the typical production control system in an American automotive plant with a Japanese production control system. In an American system, WIP would typically be held at all processes to act as a buffer against potential machine breakdowns or demand changes. Such systems tend to result in excess stock and stock in balance between processes, which leads to dead stock. Excess WIP also tends to hide problems such as machine troubles, idle time for workers, surplus workers, and excess capacity. For example, Toyota has managed to reduce lot sizes by shortening setup times, utilizing mixed-model production, using general purpose machines for increased flexibility, and other means. Important elements of the Toyota system include:

(1) The withdrawal of parts by subsequent process ("pull" system).

(2) The production and conveyance of parts in small lots.

(3) Production leveling.

(4) The elimination of waste resulting from over-production.

The Japanese attempt to use the level of WIP as a control variable to help locate problem causes and correct them.

Classical control theory techniques were used by Bradshaw and Erol (4) to develop nearly time-optimal control policies for certain types of production/inventory models. Comparison of the results of the suboptimal procedure with optimal solution for simple models, as well as computer simulation results, indicated the suboptimal control policies were not significantly slower in response time.

Wilhelm and Ahmadi-Marandi (31) address problems encountered in scheduling final assembly for manufacturing systems that produce in low volume, such as systems for the production of sophisticated weapon systems. A model was developed which is designed to assess the impact of random variations and of scheduling policies (such as those which determine launch intervals and the due dates of parts) on system performance. Measures used in the study included station idleness, schedule makespan, and queueing time for both parts and assemblies. The authors concluded that scheduling policies exert an appreciable influence on system performance. Short launching intervals were best for both probabilistic and deterministic systems. It was also shown that the average system performance was degraded by random variations, and it is important to have adequate safety times for part availability in the probabilistic environment.

Kanet and Christy (17) consider the situation where the early delivery of orders to customers is forbidden. They show that, for such systems, any managerial decision which improves any one of the following measures—mean system inventory, mean order flow time, mean order tardiness—automatically improves the other two. This is in contrast with the situation where early order departures are allowed. Collier (6) considers the impact of learning effects in the case of human operations on the performance of a production system. He concludes that improvements in operator learning characteristics can equal or exceed the benefits obtained by using strategies designed to spread setup costs (such as economic Batch Quantity).

Hax, et. al. (13), present the results of a diagnostic study which examined a firm's production/distribution system, the quality of the forecasting system, and the existing inventory levels. The first step in the study was the selection of broad areas of attention, followed by the construction of models to judge actual performance. In the areas of inventory

management, only finished goods inventory was considered. The different reasons for carrying inventory were identified, and an effort was made to estimate the needed amount of each type of inventory. Finally, an essential part of the effort to describe the existing system was to identify a minimum database which allowed the major parameters of the system to be identified in quantitative terms.

Control of WIP Inventory

Gue (11) lists the following benefits of better WIP control: (1) a reduction in late shipments, (2) a reduction in shop floor congestion, (3) a reduction in the need for emergency overtime, (4) an increase in labor efficiency, and (5) a possibility of delaying the need for expensive facility expansion. Prerequisites for a successful WIP control program include a recognition of the need for such a program, a simple system, good information, good communication, and a computer system to handle the clerical chores. Important system components, according to Gue, are a good master schedule, a properly structured product, a computer system, a good material supply system, proper system integration, and response to change.

Kelvenko (18) notes that WIP typically represents 50% to 75% of the total inventory investment. While it is true that some inventory is needed, most firms have some amount of excess inventories which have a negative impact on operations. The author notes that the variance of job flow (or queue) time increases as shop WIP (or shop utilization) increases. This results in the increased uncertainty of longer delivery times and therefore increased costs of missed delivery promises. Recommended corrective measures include: (1) scheduling delivery of purchased materials as near as possible to the required first operation start date, (2) withdrawing materials from storerooms as close to the first operation start date as possible, (3) controlling the input of work orders to the factory, and (4) deflating planning lead times, or cycle times.

Wright (29) discussed input-output control techniques as they pertain to production control. The basic principles of input-output control are as follows:

(1) It separates the planning and control of capacity from that of the production mix.

(2) It plans long-range capacity requirements for the largest possible group of items.

(3) It assigns wanted dates to individual items at the last possible moment.

(4) It never gives production new work at a higher rate than the rate of completion.

Benefits claimed for the input-output control technique include a reduction in the size of WIP queues, a reduction in lead time, and a reduction in expediting time. The method reduces WIP by ensuring the input of new work to work centers is not greater than the output of completed work. This smoothing of input makes good sense, according to the author, because WIP queues exist primarily to absorb fluctuations in input rates.

Grubbstrom (10) presents a new proposed approach for the valuation of WIP. The author contends that WIP holding costs should be derived from the resource's projected contribution to future payment, rather than from the historical costs applied to the product. The costing procedure is tested by using models of batch production, continuous production, and production line cases. The costs derived from this procedure were considerably higher than those accounted for by customary accounting procedures. This result tends to agree with experience, since holding costs are typically understated in practice.

Conway (7) used computer simulations to compare the performance of different dispatching rules with regard to various WIP performance measures. The number of jobs waiting was minimized by a modified shortest processing time (SPT) rule. Work content measures such as work remaining, total work content, etc., were minimized with rules in which the priority of a job was a ratio of imminent processing time to a sum of processing times.

Finally, Wilson and Mardis (34) suggest the use of a sequencing rule which is equivalent to SPT with jobs weighted by their dollar value, to reduce the value of WIP. They performed simulation experiments which showed that introducing value weighing into more complex dispatching rules is effective in reducing the average WIP inventory.

Conclusions

A review of the literature dealing with various issues of production and inventory control has pointed out several important factors regarding these systems. The importance of having a well-designed system cannot be overemphasized. It would be a rare thing indeed to find a company which managed its inventories efficiently and effectively with a poorly designed PIC system. An important part of such a system is measuring inventory performance. The most widely cited performance measures for measuring and managing WIP inventory are shown in Figure 2.

Bill of Material Accuracy **Inventory Accuracy** **Production Rate vs Forecast** **Routing Accuracy**	**Accuracy**
Capacity Utilization **Inventory Turnover**	**Productivity**
Schedule Dates Met **Shipment Schedules Met** **Vendor Delivery Dates Met**	**Tardiness**

Figure 2: Common WIP Performance Measures.

These can be grouped into three classes: accuracy, productivity, and tardiness. Accuracy measures include bill of material accuracy, inventory accuracy, production rate vs forecast, and routing accuracy. Such measures emphasize the fact that production and inventory control is only as good as the inputs to the planning and scheduling process. Productivity measures include capacity utilization and inventory turnover. Productivity is used to measure the relationship of output to inputs and indicates the efficiency of the production process or its component. Tardiness measures include schedule dates met, shipment schedules met, and vendor delivery dates met. Tardiness measures are calculated as positive deviations from a scheduled date and are appropriate when penalties are incurred if due dates are missed but costs are not incurred if a task is completed before its due date.

Inventory turnover is the only performance measure which directly monitors WIP inventory. The other measures may be

useful in an indirect way, but they do not appear to be effective monitors of WIP management.

The amount of liquidated progress payments during a base period is a measure of a contractor's output and the average unliquidated progress payments are a measure of the government owned WIP used by a contractor to produce that output. Therefore, the ratio of these two values, WIP turnover, should reflect how effective management has been in controlling WIP, where higher values of the ratio indicate better management of these two values. The obvious conclusion is that WIP turnover as defined here is an excellent indicator of the efficiency and effectiveness of a manufacturer production and inventory control system in managing government owned work in process.

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Continued from 20

architecture responsive to the support needs of the SDS. Additionally, based on a projected first-phase deployment for the SDS in the mid- to late-1990s, the technology for the initial capability to perform on-orbit maintenance and servicing will be at hand. The SDS will be a system of unsurpassed size and complexity in terms of technology, cost, producibility, and supportability challenges. On-orbit maintenance and servicing will answer the supportability challenge and take Air Force logistics into the twenty-first century.

Notes

[1] An element is defined as a system within the overall SDS, such as the space-based interceptor or boost surveillance and tracking system.

[2] System Concept Paper for the Strategic Defense System (S), 1 August 1987.

[3] Strategic Defense System Program Support Plan for Air Force Systems (Revision 1), 28 August 1987, p. 15.

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[10] Moss, et al., p. 100.

[11] Ely and Hatleberg, pp. 98-100.

[12] *Designing an Observatory for Maintenance in Orbit*, Marshall Space Flight Center Document 1186, pp. 6-7.

[13] Ely and Hatleberg, pp. 100-101.

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